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INDEX TO VOL. XIV

AUTHORS

SUBJECTS

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ORIGINAL ARTICLES

PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

VI. MINERAL NUTRITION: (B) NITROGEN

By R. D. Rege, B.A., M.Sc. (Bom.), Ph.D. (Lond.), A.I.I.Sc., Crop Physiologist, Sugarcane Research Scheme for Deccan*, Padegaon and S. K. Sannabhadti, B. Ag. (Bom.), Graduate Assistant

(Received for publication on 18 October 1943)

(With three text-figures)

Part IV of this paper [Rege and Sannabhadti, 1943], deals with the response of the sugarcane plant to phosphatic manuring which is found to depend upon the initial phosphatic status of the soil. It has been further explained that although certain soil types may show a deficiency of this element at start, necessitating its application, it is soon set right after growing a few sugarcane crops owing to the gradual accumulation of phosphates in the soil from oil cakes which are generally applied as a nitrogenous fertilizer to cane. The total uptake of phosphate by the plant is very low as compared to that of either nitrogen or potash and as the phosphate is scarcely leached down by irrigation all its continuous application is considered unnecessary. On the other hand, in the case of nitrogenous manuring, the general experience is that the crop invariably responds to this manuring quite markedly, independent of the initial nitrogen status of the soil. Consequently the cultivation of sugarcane involves normally a large expenditure on nitrogenous manures alone, doses from 400 to 600 lb. of nitrogen being not uncommon. It is estimated that under normal conditions about 45 per cent of the total cost of cane cultivation is incurred on nitrogenous manures alone. The question of evolving a method of proper manuring was therefore of the utmost importance and with the object of investigating this and other related problems, the Bombay Department of Agriculture established in 1893, an experimental farm at Manjri, at which, after much field experimentation, was evolved the well-known Standard Manjri Method of cane cultivation [Anonymous 1929]. This method recommended sunn green manuring, and a top dressing of 150 lb. N in equal proportions of sulphate of ammonia and oilcakes to be applied in three equal doses—the first in the form of sulphate of ammonia alone at three weeks after planting, the second at eight weeks after planting in a mixture of sulphate of ammonia and oilcakes on equal basis, and the third in the form of cake alone at earthing up time.

This recommendation of total nitrogenous dose was mainly based on economic considerations and was thus found to be of limited applicability. Further the newly introduced high-yielding varieties of sugarcane demanded higher manuring. It was, therefore, realized that in order to evolve a sound system of manuring a thorough investigation was required of (1) the precise quantities of mineral elements absorbed by a normally developed plant, (2) the optimum ratio of these elements beyond which an excess or deficiency of any one element would produce a disturbance in the metabolism of the plant, and (3) the ultimate fate of the fertilizers applied to the plant. This research has been in progress for January-planted cane under the Sugarcane Research Scheme since its inception in 1932 and the work on nitrogen nutriment carried out during the first four years is dealt with in these pages.

Outline of the scheme

All the detailed investigation on the nitrogen nutriment of cane described in these pages has been conducted in soil type B from among the eight soil types in which the soils of the Deccan Canal tract are classified by Basu and Sirur [1938]. This type possesses a dark grey surface soil with an admixture of brown colour and a preamble subsoil which is coloured reddish brown. It is well supplied with calcium carbonate which varies from 9 to 12 per cent, while the nitrogen content is low, being round about 0·045 per cent. The total phosphate is about 0·1 per cent. Field experiments carried out during the first few years showed a distinctly favourable effect of phosphatic manuring and as a result in 1936-37 a dose of 100 lb. P_2O_5 in the form of double superphosphate was given as a basal dressing to all the treatments. The nitrogenous treatments varied from 75 lb. to 600

* This scheme is partly subsidized by the Imperial Council of Agricultural Research

lb. N in graduated doses. It was felt that only through such wide range of treatments would the metabolic effects of nitrogen on cane plants be clearly brought out.

Owing to limitations of space for field experiments and the staff for the analytical work, all the variations in doses could not be tried simultaneously. During the first two years, doses up to 300 lb. N in the variation of 75, 150 and 300 were studied and later on the number of treatments were augmented to five by including higher doses and dropping some lower ones. During all these four years, two varieties—Pundia and POJ 2878—were studied, the former being non-flowering, late maturing and shallow-rooted and the latter flowering, early maturing and deep-rooted. During the first two years, the nitrogenous quantities were applied, in equal proportions of sulphate of ammonia and oilcakes divided in three doses as recommended in the Standard Manjri Method. Finding, however, some deleterious effect of this method of application in higher nitrogenous top dressings, the proportion of sulphate of ammonia to oilcakes was changed to one-third and two-thirds and the distribution to four doses in later years. The methods of cultivation, planting, irrigation, etc., were kept the same as recommended in the Manjri Standard Method. There were duplicate plots per treatment, the plot side being 28 ft. × 38 ft. with cane rows four feet apart. From September onwards, lodging of cane was observed in higher nitrogenous treatments and was specially severe in Pundia.

Detailed observations were taken on the developmental behaviour of the crop and some physiological characteristics. In addition to periodical botanical observations on the standing cane for the determination of the rate of growth, plants were also periodically cut on an area basis for yield per acre and also uptake of nutrients, the normal constituents determined being N, P, K and Ca. Owing to limitations of space, it is not proposed to discuss always the data of each year separately. Wherever possible, it will be dealt with in a general way for all the graduated doses under study after making due allowance for the seasonal fluctuations on the basis of the treatment of 300 lb. N which was common to all the four seasons. The methods used in field observations and analytical work were the same as described in Part IV of this paper.

Experimental

A. Developmental studies

Germination. It has been shown by Rege and Wagle [1939] that although the reserve material in the seed piece exercises an important control on the process of germination, application of sulphate of ammonia at planting is beneficial as it accelerates the germinative capacity conducive to higher germination. The bulky manures as sunn green manuring or compost are not of any use in this respect. This will be evident from Table I in which the results of two separate experiments are illustrated.

During the first season the variety was POJ 2878 and in the second Co. 419. In the case of

Table I

Periodic data of germination

(Per cent of the total number of buds planted)

Treatment per acre	1938-39		1939-40	
	3 weeks	8 weeks	3 weeks	8 weeks
(1) Sunn green manuring	$36 \cdot 3 \pm 1 \cdot 3$	$77 \cdot 5 \pm 0 \cdot 99$	..	..
(2) Sunn green manuring+300 lb. N.	$42 \cdot 1 \pm 0 \cdot 76$	$82 \cdot 3 \pm 4 \cdot 9$	..	..
(3) No manure	..	..	$22 \cdot 7 \pm 5 \cdot 20$	$56 \cdot 7 \pm 4 \cdot 00$
(4) Compost 20,000 lb.	..	..	$21 \cdot 7 \pm 4 \cdot 07$	$59 \cdot 5 \pm 6 \cdot 30$
(5) Compost+300 lb. N..	..	..	$36 \cdot 8 \pm 3 \cdot 96$	$64 \cdot 9 \pm 3 \cdot 66$
(6) 300 lb. N.	..	..	$30 \cdot 7 \pm 3 \cdot 66$	$66 \cdot 7 \pm 3 \cdot 96$

top dressings of 300 lb. N one-tenth of the dose, i.e. 30 lb. N was applied at planting time in the form of sulphate of ammonia alone. In our experimental work on nitrogen nutriment this procedure was adopted in all the treatments varying from 75 to 600 lb. N. It was observed that only in the case of 75 lb. N in which the planting dose was 7·5 lb. N the germination was low, the figure in POJ 2878 at eight weeks count being $80 \cdot 6 \pm 3 \cdot 2$ as against $88 \cdot 7 \pm 3 \cdot 4$ in the case of 150 lb. N. On the other hand, all the higher treatments have equalled this

treatment of 150 lb. N. The minimum dose required for securing the optimum germination is thus 15 lb N as sulphate of ammonia and increasing this quantity even up to 60 lb. N has been found to be of no further advantage.

Tillering and borer counts. Besides periodical counting of the total population, the method of labelling all tillers emerging from a germinated bud was adopted in the case of ten randomly selected plants per treatment in order to get a correct idea about the influence of treatments on the tillering capacity and the ultimate fate of the tillers so formed. As the latter method has brought this out more clearly than the former, these data are only presented according to the month of the appearance of tillers and their ultimate success (Tables II and III). The figures are given for the first two seasons only as in later seasons the tillering performance has been quite similar in all the treatments owing to the dropping of the lowest nitrogenous dose of 75 lb. N from further investigation.

TABLE II

Tillering performance 1934-35

Treatment	April		May		June		July		Total per cent success	Ratio of tillers to mother cane
	Per cent of total tillers formed	Per cent tillers successful	Per cent of total tillers formed	Per cent tillers successful	Per cent of total tillers formed	Per cent tillers successful	Per cent of total tillers formed	Per cent tillers successful		
POJ 2878										
75 lb. N	39·1	10·8	50·0	8·7	10·9	4·3	..	..	23·8	4·6
150 lb. N	55·4	28·1	38·6	3·5	7·0	..	..	..	31·6	5·7
300 lb. N	50·0	25·9	37·0	9·3	13·0	1·8	..	..	37·0	5·4
Pundia										
75 lb. N	40·3	10·5	35·1	8·7	24·6	5·3	..	..	24·7	5·7
150 lb. N	34·9	14·3	33·3	6·4	30·2	4·8	1·6	..	25·5	6·3
300 lb. N	21·4	7·1	30·4	5·4	37·5	6·3	10·7	1·8	20·6	12·2

TABLE III

Tillering performance 1935-36

Treatment	April		May		June		July		Total per cent success	Ratio of total tillers to mother cane
	Per cent tillers formed	Per cent tillers successful	Per cent tillers formed	Per cent tillers successful	Per cent tillers formed	Per cent tillers successful	Per cent tillers formed	Per cent tillers successful		
POJ 2878—										
75 lb. N	48·8	14·0	48·8	0·0	..	..	2·3	0·0	14·0	4·3
150 lb. N	66·0	21·2	17·0	4·3	2·1	0·0	14·9	2·1	27·7	4·7
300 lb. N	42·9	12·5	48·2	10·7	..	..	8·9	0·0	23·2	5·6
450 lb. N	48·0	24·0	30·0	10·0	14·0	0·0	8·0	0·0	34·0	5·0
600 lb. N	40·0	16·9	41·5	12·3	3·1	0·0	15·4	0·0	29·2	6·5
Pundia—										
75 lb. N	41·2	17·6	47·1	11·8	5·9	0·0	5·9	0·0	29·4	5·1
150 lb. N	38·6	14·0	56·1	10·5	..	..	5·3	0·0	24·6	5·7
300 lb. N	36·8	36·8	54·4	1·8	..	..	8·8	1·8	40·4	5·7
450 lb. N	41·6	10·3	41·4	12·1	8·6	0·0	3·7	0·0	24·1	5·8
600 lb. N	26·3	21·1	61·4	10·1	5·3	3·5	7·0	0·0	35·1	5·7

In general it may be stated that early formed tillers, i.e. those formed in April and May, come out more successful than later ones. Coming to the data of individual seasons, the data of the first season (Table II) has brought out clearly the varietal characteristics. In the case of Pundia there is an increased tillering with increased top dressings which in the treatment of 300 lb. N reached such an abnormal figure as 12·2 tillers to one of mother plant. The periodical harvest data which will be discussed under (c) have further shown greater production of leaf than cane in this treatment and it was mainly the smothering of a large number

of tillers during the process of earthing which was conducive to the normal performance of growth later. This abnormal behaviour of the plant at the tillering phase in this high nitrogenous series appears to be due to the high concentration of nitrogen in the soil solution as a result of the adoption of the Standard Manjri Method in the distribution of top dressings. According to this method of distribution the crop received 200 lb. N within two months from planting, out of which 150 lb. N was in the form of sulphate of ammonia alone. This has affected adversely Pundia and not POJ 2878 which, it seems, can withstand higher concentration of soil solution. This is further confirmed by the data of the next season (Table III) in which the proportion of sulphate of ammonia to cake as well as the distribution of the total dose were modified by reducing the quantity of sulphate of ammonia to one-third from one-half of the total dose, and increasing the distribution to four times instead of three. With this modification, even in the case of 600 lb. N, in which the maximum quantity received within two months as sulphate of ammonia was 100 lb. N. only, the abnormal stimulus to tillering is not visible. The low availability of nitrogen reduces the tillering capacity, the limit of nitrogenous top-dressings being 150 lb. N in this respect. On the other hand it has already been shown [Rege and Sannabhadti, 1943] that a basal dose of 100 lb. P_2O_5 accelerates the tillering capacity even in the absence of nitrogenous top dressing and it is only at the growth phase that deficiency of nitrogen comes into prominence causing death of most of the tillers. It is thus apparent that so far as the tillering phase is concerned, phosphates are more important and can even obliterate the adverse effect of the deficiency of nitrogen.

No definite conclusion could be drawn from the data of borer infestation owing to a great deal of fluctuation in the figures obtained for the different treatments. The only outstanding factor which has emerged from these data is that Pundia is more susceptible to borer attack than POJ 2878.

Growth. The profuse tillering in Pundia during the first season in the case of 300 lb. N had not only adversely affected the total production in mid-June by reducing it by 48 and 20 per cent as compared to the lower treatments of 75 and 150 lb. N respectively but had further shown an abnormal rise in the ratio of the weights of the functioning leaves to stem, the figure being 33·6 as against 6 in the lower treatments. In the case of POJ 2878 no such abnormality could be traced, the ratios for both 150 and 300 lb. N being practically similar and only slightly higher than that for 75 lb. N. During the next season also no abnormal differences in the ratios could be observed between the treatments varying from 75 to 600 lb. N in the case of both the varieties. The adoption of the standard method of manuring in such heavy doses has evidently been mainly responsible for the leafy growth, and this is amended by the modification in manuring followed during the next season. In the present case also, the method of using oil cakes for manuring just before earthing followed by this operation of earthing up has been beneficial in correcting the early adverse effect of manuring. Earthing up has not only smothered many of the tillers but has checked further tillering, thus reducing the ratio of leaves to stem practically to the same figures obtained in the lower treatments. Further, manuring with oilcake has helped to keep down the concentration of soil solution to the beneficial limit, owing to its slow availability and as a result, from August onwards, this treatment has put on pace in growth, coming eventually superior to others in the end.

In order to find out the optimum concentration of nitrogen in solution for securing best growth, a sand-culture experiment was conducted with salt solution consisting of three variations of nitrogen on the basis of the one-third dose of the treatments of 150, 300 and 600 lb. N. Sulphate of ammonia was used to supply nitrogen, while other salts as phosphate, potash, etc. were supplied in the form of usual standard chemicals. There was a control treatment consisting of water alone as well-water was used for dilution of the salt cultures. Pots were of Jubbulpore burnt clay and there were four pots for each treatment. The application of culture solutions was started immediately after germination and was continued for three months, at the end of which period the crop was harvested. The data are given in Table IV.

The above data show that for the best growth an optimum concentration of sulphate of ammonia equal to 50 lb. N per acre is essential. No doubt this quantity will be slightly more in the case of soil in order to compensate for its adsorbing power; but concentrations above 100 lb. N are found to be definitely injurious to varieties like Pundia. In the case of POJ 2878, although 50 lb. N has come out the best, the next concentration equal to 100 lb. N (one-third of the treatment of 300 lb. N) has also given significantly better results than control. This variable response of the varieties to the concentration of nutrients seems to be due to

TABLE IV

Sand culture series 1935-36

Treatment and variety	Oven dry weight per pot in gm.		
	Aerial portion	Roots	Total
POJ 2878			
Control	16·0	6·3	22·3
150 lb. N	93·1	11·6	104·7
300 lb. N	64·4	7·6	72·2
600 lb. N	40·3	3·8	44·1
Pundia			
Control	9·5	3·0	12·5
150 lb. N	31·4	5·1	36·5
300 lb. N	16·3	2·1	18·4
600 lb. N	7·5	1·7	9·2
C. D. between any two treatments	..	..	22·5

the differential permeability of roots of these varieties. The determination of the osmotic pressure of the sap collected from the roots of these varieties has, in fact, shown it to be 26 per cent higher in the case of POJ 2878 than that in Pundia.

The relative growth rate per stool per day which is calculated according to Fisher's formula [1932] from the monthly production of total dry matter (inclusive of dry, green leaves and stem) is illustrated on a percentage basis in Fig. 1 for the season 1935-36. This season was selected for illustration mainly because both the lowest and the highest treatments under investigation were present and secondly monthly samples beginning from fourth month were

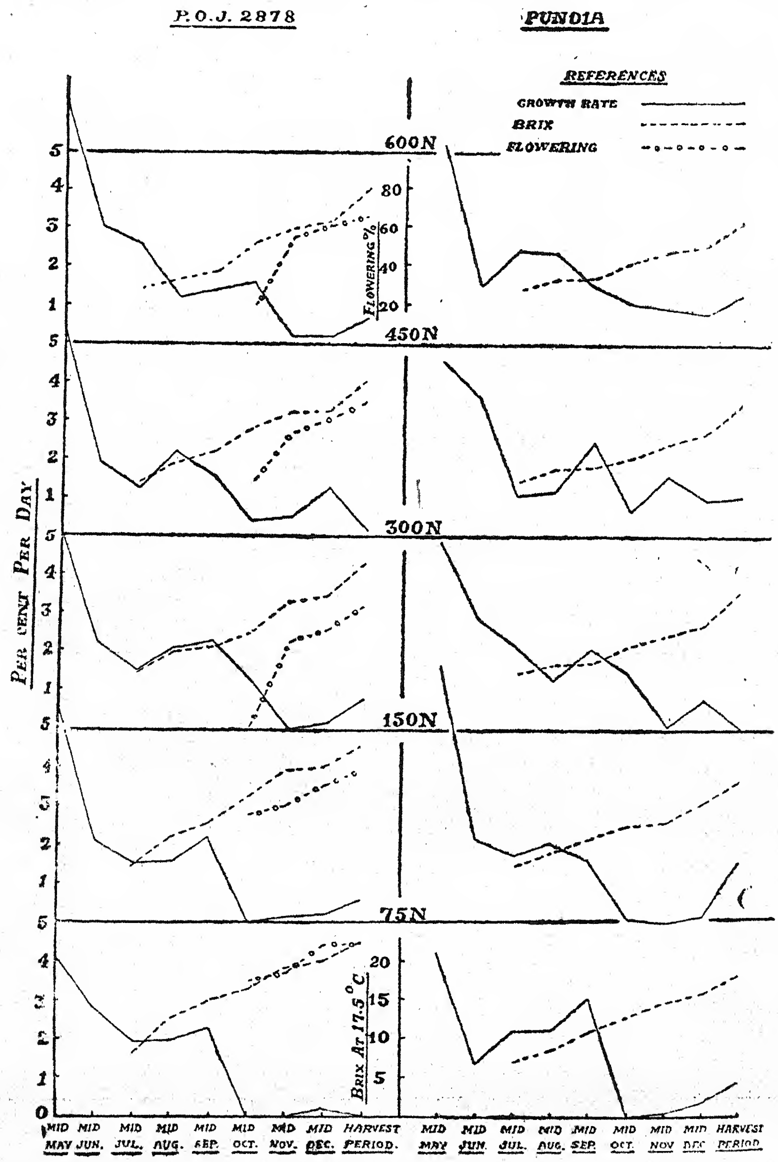

FIG. 1. Relative growth rate (Fisher's Formula)

collected for the determination of growth only during this season. During later years the lowest treatment of 75 lb. N was dropped and further the periods of sampling were reduced to five depending upon the plant phases. The comparison of the data of the relative growth rate has, however, shown trends similar to those illustrated above. There are two peaks in general, the first showing the highest rate. The second peak, which comes by about September, coincides with the grand period of growth if one considers the actual increase in weight irrespective of the previous weight which is the basis of the calculation by this formula. Coming to the treatments, two facts emerge quite clearly. Up to about eight months the relative growth rate is practically similar in all the treatments except in 75 lb. N which has shown a slower rate at start. In the case of lower treatments as 75 and 150 lb. N the growth practically ceased after this period. This cessation of growth occurred a month later in the case of 300 lb. N, while in the higher treatments it was not observed throughout. In the case of the flowering variety (POJ 2878) the continuation of growth seems to be due to the slow rate of flowering in these higher treatments, (see curves for flowering). The spurt in growth in most of the treatments in the end may be due to the inclusion of water shoots of which separate record was not kept at the time. Das [1936] had also come to similar conclusion in his experimental work with three series of low, medium and high nitrogenous manuring. According to him all these series grew at about an equal rate until the ninth month and then the low N series began to lag behind the other two.

The figures for final dry weight (col. 2, Table V) show an upward gradient with increasing doses of nitrogen. They are also a good illustration of the law of diminishing returns as could be evident from the figures of percentage increase given in col. 3, Table V. Although the growth has practically ceased at the same time in 75 and 150 lb. N, its slow rate at start coupled with the low tillering seems to have been responsible for the lower yield in the case of the former treatment.

In Table V also, the data of some of the physiological characteristics have been given. The number of leaves and their measurements are the average of the ten periodic samples. The carbon assimilation is determined by the Ganong's punch method [1908] and the figures are the average of five monthly estimations till September. This procedure of averaging out has been followed firstly because it has enabled us to present the data within limited dimensions and secondly it has smoothened out the periodical fluctuations thus revealing the real differences between the treatments. However, whenever there has been some consistency in the periodic

TABLE V

Some physiological characteristic per stools, 1935-36

Treatment and variety	Final total dry wt. in gm.	Per cent increase	Average No. of functioning leaves	In inches: Average length per leaf (L)	In inches: Average breadth per leaf (b)	In square inches: leaf area (L × ½ b)	In square inches: Total area per stool	Dry wt. per sq. in. of leaf surface (gm).	Carbon assimilation per cent	Final ratio of total leaves to stem	Final ratio of dry leaves to green leaves
1	2	3	4	5	6	7	8	9	10	11	12
POJ 2878—											
75 lb. N	853	100·0	16·9	44·1	1·99	43·8	740	0·153	9·4	0·84	3·59
150 lb. N	1162	135·0	18·6	47·8	2·17	51·8	963	0·145	9·2	0·57	1·87
300 lb. N	1386	162·3	20·5	51·0	2·25	57·4	1177	0·142	7·9	0·59	1·19
450 lb. N	1593	186·7	20·6	52·7	2·37	62·5	1288	0·141	8·2	0·48	0·98
600 lb. N	1642	192·5	24·3	49·8	2·33	58·0	1409	0·140	11·3	0·46	0·93
C. D.	337	...	3·2	2·4	0·33	...	...	...	...	...	...
Pundia—											
75 lb. N	1227	100·0	20·4	50·0	1·90	47·5	969	0·135	12·7	0·57	1·41
150 lb. N	1444	117·7	25·9	52·4	1·84	48·2	1248	0·140	12·2	0·44	1·09
300 lb. N	1619	132·0	27·8	53·5	1·95	52·2	1441	0·136	11·3	0·46	0·93
450 lb. N	1749	142·5	28·3	53·7	1·94	52·1	1474	0·132	14·7	0·46	0·75
600 lb. N	1906	155·3	28·1	54·5	1·96	53·4	1501	0·123	15·3	0·50	0·59
C. D.	406	...	3·5	1·48	0·18	...	...	...	...	...	...

fluctuations these have been referred to during the course of the discussion.

The data show that there has been a progressive increase in the number of functioning leaves with increasing applications of nitrogen, the significance being only observed between 75 lb. N and 300 lb. N and above in the case of POJ 2878 and 75 lb. N and all others in Pundia. The leaf area per leaf is also similarly affected. This has been, in fact, the case in practically every periodic sampling. It will be further seen that both the length and breadth of functioning leaves are favourably influenced by the nitrogenous manuring, the optimum figure being about 300 lb. N. This does not agree with the findings of Das [1936], who states that the treatment differences on width are the reverse of those on length, the high N series having the widest leaves. Studies of periodic figures have shown that both blade length and width have increased in all the treatments from month to month up to July, i.e. first six months, and then have remained constant for a period which has varied according to the treatments and varieties. Thus in the case of POJ 2878 this period lasts for about three months, i.e. till September, in the lower treatments of 75 and 150 lb. N while it extends till December in the higher ones. This seems to be due to early start in flowering in the lower treatments. No such variation between treatments is observed in Pundia even till the end in all the treatments, the leaf area per treatment remaining practically constant from July onwards till the end. This shows that the size of the leaf is a function of the age of the plant and is further controlled by the climatic and nutritional conditions. The maximum leaf area occurs at the climatic conditions most suited for the plant growth. Further, as long as the availability of nitrogen continues this maximum size of the leaf continues and with its deficiency it diminishes. The rate of carbon assimilation (col. 10, Table V) which represents the percentage increase in dry weight at 3 p. m. over 8 a.m. does not show any significant variation between the treatments. When one, however, considers, the leaf area, the effect of increased nitrogen on total carbon assimilation is evident. This is in agreement with the findings of Gregory [1926], who working with barley has shown that only the leaf area increases and not the assimilation rate with increased nitrogen.

The figures for dry weight per square inch of the leaf surface distinguish the treatments of 75 and 150 lb. N from the higher ones by their greater weights. According to Russell [1937], greater quantities of nitrates lead to the development of large dark green leaves which are often crinkled and soft because of the thinning of the walls or of changes in tissues. It has already been stated that higher manuring had led to an increase in leaf area mainly up to a limit of 300 lb. N. There was also a development of green colour which was more evident in the case of Pundia than in POJ 2878, but it was not combined with the crinkled appearance even in the highest manurial dose. In the absence of anatomical studies, however, nothing can be stated as regards the differences in the cell structure.

The ratio of total leaves to stem (col. 11, Table V) reveal a greater production of stem than leaves in the end with increasing nitrogen in the case of POJ 2878 and practically a constant figure for Pundia in treatments above 75 lb. N. This increased production of stem would be of commercial advantage as the stems form the raw material for the production of *gur* or sugar. A similar instance has been given by Russell [1937] for mangolds in which increased roots are obtained by increased nitrogen while swedes sugarbeet and potato crops produce more leaves. In the case of sugarcane one must, however, remember the operation of earthing up which smothers the excessively formed tillers and it would be very interesting to see whether the same results would have been obtained in case this operation would have been dropped. The proportion of dry leaves to green leaves support the well-established fact of the deferment of the yellowing and death of the leaves with increased nitrogen.

In order to find out how far the first order stalks or mother canes and tillers formed during different months contribute to the total cane weights per stool in the end, individual stalks from ten stools labelled for tillering were separately weighed and their percentage contribution calculated. Owing to borer attack the number of stools under observation are not sufficient to yield conclusive evidence above the effect of the various treatments. The figures have, however, shown that the contribution from the first order stalks varies between 30 to 40 per cent in the case of POJ 2878 and 15 to 20 per cent in the case of Pundia except in some lower nitrogenous doses. The rest of the weight is practically made up by tillers formed in April and May. It has been further observed from the weight of the individual canes that generally the growth of the mother cane is poorer than that of April-formed tillers and even tillers formed in May have shown the same trend in the

case of higher nitrogen in Pundia. These tillers have also attained practically the same brix as the mother canes at harvest and as such their contribution to the tonnages of both cane and sugar per acre would be considerable.

The periodical strip sampling is utilized for the estimation of tonnage as well as mineral requirement per acre, which is of great practical importance for the evolution of a manuring system. For this purpose, sampling of 3 ft. length strips is found to be more reliable than the usual method of stool sampling, mainly because there is a very large reduction in the number of stools per acre with the advance in crop growth owing to the mortality of stools either by borer or other extraneous causes, which could not be accurately determined, except without disturbing the soil and roots at the base of the plant, once the full tillering is attained and the crop is earthed up. Thus it was found that on an average in POJ 2878 there were 19,965 stools per acre at four months from planting, 13,798 at eight months and 12,342 at twelve months. The calculation of cane tonnages or their mineral requirement on the first count of stools at four months only, when counting could be done without disturbing the plant, would thus give abnormal results. During strip sampling, however, the number of stools per strip were carefully counted, the number of strips for each sampling time being eight during the early stages of crop growth and five later. The cane tonnages at harvest only are represented in Tables VII and VIII for 1935-36 and 1936-37 with the data of maturity as well. During the latter season a basal dose of phosphate was applied and its effect is visible specially in lower nitrogenous series. In general there is an increase in tonnages with increased doses even up to 600 lb. N, specially in POJ 2878, the rise being steeper up to 300 lb. N than in higher treatments. Large-scale replicated trials conducted for three years with varying doses up to 375 lb. N have, however, shown no significant increase in cane tonnages in 375 lb. N over 300 lb. N. The data (average of three years) are given in Table VI. Instead of Pundia the variety under trial was Co. 419, it also being a late-maturing one.

Root system. The effect of increased dose of nitrogen on the root system has already been discussed in detail in a previous paper by Rege and Wagle [1941]. In general it may be stated that there has been a reduction in the root system with increasing nitrogen, thus exhibiting an inverse relationship with the stool weights. The distribution of roots in the various soil depths have shown more intensity in the lower depths in higher manuring. It is suggested that this may be meant to support the high weight of the cane with a view to preventing its lodging.

Maturity. This is judged by monthly estimation of Brix from mid-September onwards. These data are illustrated in Fig. 1 for the season 1935-36. Detailed analyses for sucrose and glucose are carried out for a few periods and are given in Table VII. It would be seen that the effect of treatments is more clearly brought out by these detailed analyses than by the figures of Brix alone. Even in cases where the figures for Brix are similar (col. 8, Table VII under Pundia) for all the treatments, there has been a definite fall in sucrose in treatments of 300 lb. N and above. The low figure for sucrose at harvest time in the treatment of 75 lb. N in the case of POJ 2878 seems to be due to its remaining in the field long after its attainment of maximum maturity. The other treatments have

TABLE VI

Harvest data (1939-1942)

(Average of six replicates per season)

Treatments	Cane (Tons per acre)	Sucrose per cent	C.C.S. per acre	Period of harvest
POJ 2878				
225 lb. N	39·55	16·28	5·59	First week of February
300 lb. N	43·51	15·97	5·91	
375 lb. N	46·99	15·34	6·41	
CO. 419				
225 lb. N	54·84	14·76	6·57	Fourth week of February
300 lb. N	59·31	13·56	6·33	
375 lb. N	62·12	12·93	6·23	
C. D.	4·45	..	0·57	

shown a tendency towards rise in sucrose and it was, therefore, felt that delaying of harvest might still increase the sucrose content further. In order to test this, the crop was continued in the field during the following season with periodical sampling till end of April (Table VIII). In POJ 2878, 150 lb. N attained the maximum maturity by the end of February while the rest

Table VII

Periodical maturity tests

(Percentage on cane juice 1935-36)

Treatment	Mid-September			Mid-November			Harvest time					
	Brix at 17·5°C	Sucrose per cent	Glucose per cent	Brix at 17·5°C	Sucrose per cent	Glucose per cent.	Brix at 17·5 °C	Sucrose per cent	Glucose per cent	Yield tons per acre	C. C. S. tons per acre	Date of harvest
1	2	3	4	5	6	7	8	9	10	11	12	13
POJ 2878—												
75 lb. N	14·7	10·4	1·96	19·0	17·7	0·62	20·9	17·5	0·73	28·1	3·27	31-1-36
150 lb. N	12·9	8·6	2·67	19·9	17·6	0·78	21·8	18·9	0·49	37·8	4·97	Do.
300 lb. N	10·4	5·2	3·63	16·6	13·1	2·10	21·9	18·4	0·87	45·4	5·62	1-2-36
450 lb. N	10·7	5·0	4·12	15·9	12·3	2·23	20·7	16·6	0·92	45·8	4·96	Do.
600 lb. N	9·4	4·1	4·25	15·0	10·7	2·23	20·2	16·4	1·02	49·3	5·34	Do.
Pundia—												
75 lb. N	10·9	5·6	4·00	14·9	11·5	2·10	18·7	16·0	1·21	34·0	3·80	24-2-36
150 lb. N	10·7	5·8	4·76	13·0	9·2	3·10	18·9	16·4	1·14	38·0	4·42	Do.
300 lb. N	8·4	2·6	4·78	11·9	7·8	3·25	18·4	14·6	2·04	50·8	4·86	4-3-36
450 lb. N	8·9	2·9	7·29	12·1	7·4	7·41	18·8	14·5	2·50	50·1	4·77	Do.
600 lb. N	8·7	2·5	7·43	12·0	7·3	7·41	18·5	13·1	3·48	52·1	4·17	Do.

Note. C. C. S. is calculated according to the Srivastava's formula

$$\frac{3P}{2}\left(1-\frac{10+F}{100}\right)-\frac{B}{2}\left(1-\frac{6+F}{100}\right)$$

Table VIII

Periodical maturity tests

(Percentage on cane juice 1936-37)

S. No.	Treatment	Cane yields (tons per acre)	26 Feb. 1937		29 March 1937			17 April 1937		27 April 1937			C. C. S. tons per acre
			Brix at 17·5°C.	Sucrose per cent	Extraction per cent	Birx at 17·5°C	Sucrose per cent	Brix at 17·5°C	Sucrose per cent	Extraction. per cent	Brix at 17·5°C	Sucrose per cent	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	POJ 2878 .												
1	150 lb. N . .	36·0	23·2	21·4	36·3	22·3	20·7	21·8	19·8	26·1	19·6	17·8	5·45
2	225 lb. N . .	42·4	21·9	19·7	40·5	22·0	20·0	20·3	18·5	24·2	19·6	17·8	5·97
3	300 lb. N . .	44·1	20·9	17·7	40·6	22·6	20·5	20·5	18·5	22·1	19·1	17·3	6·41
4	450 lb. N . .	45·5	20·6	17·9	43·4	22·2	19·9	19·8	17·8	25·2	19·3	17·4	6·39
5	600 lb. N . .	49·4	19·7	17·0	47·0	21·4	18·9	17·4	15·0	28·1	17·0	14·6	6·57
	Pundia—												
6	150 lb. N . .	42·9	19·7	16·5	53·1	19·1	16·8	17·8	15·0	33·8	16·7	13·8	4·88
7	225 lb. N . .	45·4	18·7	16·2	55·0	18·5	16·5	18·9	15·9	39·0	19·8	15·7	5·01
8	300 lb. N . .	55·7	17·4	14·3	51·1	17·5	14·9	18·4	14·8	39·6	19·3	15·3	5·58
9	450 lb. N . .	53·2	16·5	12·7	55·2	17·1	12·3	17·8	14·6	38·8	16·2	14·0	5·36
10	600 lb. N .	54·8	17·2	13·0	57·1	16·8	12·6	14·3	12·4	41·2	16·5	12·9	4·72

showed rise till the end of March followed by a fall in April with the rise in temperature. Further the highest figure of sucrose is observed in 150 lb. N closely followed by treatments of 225, 300 and 450 lb. N, while the last one has shown a drop by about 1 per cent. In the case of Pundia, the highest figure for sucrose is observed in samples taken on 29 March in the treatments of 150 and 225 lb. N only. The other treatments showed some rise in later samplings, but even till last the figure did not come up to this maximum one except in the case of 300 lb. N. Besides in these later samplings, there is an appreciable fall in extraction (cols. 5 and 10, Table VIII) due to increase in pithy fibre and formation of cavity in the centre of the stem, which are more pronounced in the case of POJ 2878 than in Pundia. These findings are of great economic importance in that, although increased quantities of nitrogen may yield some increase in cane tonnages, they bring about delay in sucrose formation, which owing to short period of favourable climate, may not thus be able to give equally higher yields of sugar—an important commercial product.

The figures for commercial cane sugar given in the last column in both the tables are calculated on the basis of analytical results at harvest time for 1935-36 and on maximum maturity for the next season. The comparison of the two years' data clearly shows the advantage of harvesting at the time of maximum maturity as even in the case of the same tonnages it has given from 0·5 to 0·8 tons sugar more per acre during the latter year. These figures further give a clear idea of the limits of nitrogenous applications. In this respect varieties differ in their response according to their inherent characteristic of sucrose development. Thus, while in the case of early-maturing variety as POJ 2878 one can go up to 600 lb. N, this last dose of nitrogen is definitely deleterious in the case of the late-maturing variety as Pundia. Similar will be the result with Co. 419 which is at present a leading cane in the Deccan Canal Tract as it also is a late-maturing variety. On economic considerations 300 lb. N appears to be the optimum dose for this planting in the case of all the varieties.

B. Mineral nutrition

For these investigations the plant material from periodical samplings for the growth studies was used. During the maturity period a few important constituents were also determined in the cane juice and *gul*. The details of the methods are given in our previous communication [Rege *et al.* 1943]. The availability of nutrients was estimated by the periodical analysis of the soil as well as exudates obtained from cane stools. In the former case only availability of nitrogen could be tested, while in the latter N, P, K and Ca were estimated by the colorimetric method of Steenkamp [1934].

Water content. The water contents of green leaves and stems were determined every time the plant sampling was done. During 1935-36, monthly figures are available which are further averaged according to the three plant phases of formative, growth and maturity respectively. In the case of leaves, the water content is calculated both in relation to leaf area and to the dry weight, while the figures for stems are based on dry weight only. All these are given in Table IX. In general, there has been a reduction in the water content of the leaf with the progress of time in both leaves and stems when the figures of the ratio of water to dry weight are considered. Similar ratios of water to leaf area, however, show quite the reverse phenomenon in that a higher water content is observed at the later stages, the grand period stage coming out the highest in this respect. Similar data of later years have confirmed this finding. This contradiction in the figures calculated by these two methods is apparently due to the periodical variation in the dry weight per unit leaf area which is less in the beginning and increases with the advance in age. We have shown in our previous communication on phosphate that such physiological processes as photosynthesis are not at all influenced by the dry weight of the leaf. It is the leaf area which is of importance and in this respect it seems that working out the ratios of water content to leaf area, as recommended by Gregory and Richards [1929], will give a real picture of the influence of the water content on the various physiological processes than the ratios of water content and dry weight.

Coming to the individual treatments, there is practically no difference in the water content of the leaves in the formative stage in both the varieties. During later stages higher succulence is observed in the case of 450 lb. N and above in POJ 2878, while in Pundia the data have shown practically no variation. Similar results are also obtained in the case of stems. There is, however, no clear evidence as obtained by Das [1936] to show that this greater succulence in the higher treatments is of any advantage from the standpoint of growth. This may be due to continuous irrigation which this crop has

received throughout its life cycle, which has been able to maintain the soil moisture at its optimum level for the physiological processes pertaining to growth even in the lower nitrogenous treatments and therefore this higher succulence in the other treatments is not of much use. On the other hand dehydration of stems seems to have a good relation with the sucrose formation, as the treatments with lower nitrogenous manuring, which show higher sucrose content in cane, are characterized by low water content. Among the varieties also POJ 2878, which has shown higher dehydration than Pundia, contains greater sucrose.

Uptake of mineral nutrients. Only four important nutrients—N, P, K, and Ca—are estimated in the different organs of the plant except roots, whose collection free from clay particles in the case of the black cotton soil was found to be extremely difficult. The data thus obtained were calculated in more ways than one, e.g. per 100 gm. of each part of the plant, per 100 gm. of the whole plant, and on the basis of whole plant, stool as well as acre. The trends in the case of the first method of calculation have been practically the same as illustrated in our previous paper [Rege *et al.*, 1943] such as a higher fall in all the constituents in stems than in green leaves with the progress of growth and the migration of nitrogen, phosphate and potash to other parts when the leaves become physiologically inactive and dry, the highest migration being observed in the case of phosphate. Due to the limitations of space these data are not given. Only the data per 100 gm. of whole plant are graphically represented in Fig. 2. These curves for the whole plant practically reflect the total effect of the fluctuations in the different organs. Among the different nutrients nitrogen shows the highest fall followed by phosphates. For instance, taking the starting percentage figures for April as 100, the figure for January has shown about 25 per cent of this nitrogen, 45 per cent of phosphate, 68 per cent of potash, and nearly the same percentage of calcium in 100 gm. of the plant material. In the case of potash, even an increased percentage of uptake continues for a few months after April. It is thus apparent that per unit of nitrogen absorbed there is much more production of dry matter than in the case of other constituents the next in importance being phosphate. Among the varieties, a higher level of uptake of only phosphate is observed in Pundia throughout its life-cycle than in POJ 2878 with practically no difference as regards the uptake in the other constituents.

Coming to the individual treatments, the differentiation in the percentage uptake is only evident in the case of nitrogen specially at later stages of grand period and at the stage of maturity, when the nitrogenous level is much less in lower treatments than 300 lb. N and above. This is in consonance with the performance of the plant in the growth phase discussed above and clearly reveals the influence of nitrogen on this phase. As regards the other constituents the small fluctuations between the treatments do not show any definite trend, the uptake being on the whole practically similar in all the cases. This has affected the ratios of nitrogen to other constituents, which continues to be higher in the higher treatments. This unbalanced nutrition may be the reason of the continued growth and low maturity observed in such higher doses as 450 and 600 lb. N. The application of a basal dose of 100 lb. P_2O_5 as superphosphate during the following season of 1936-37 has also been ineffective in improving these ratios. This has been already shown [Rege *et al.*, 1943] to be due to the increase in the uptake of nitrogen as a result of this phosphatic application. Similar results have been obtained by Dutort and Beaker [1939], who found greater absorption of N by Co. 301 with greater quantity of P_2O_5 in the soil.

From the standpoint of the practical agriculturist the total uptake per acre is of importance and is therefore given for a few periods in Table X. As the optimum uptake varied according to the treatments from October to December, the figures under this heading represent the uptake in different months and not at the harvest time, as all the constituents at this time show a fall. It seems that as the cane attains maturity there is a return of plant food to the soil and harvesting the crop at its maximum maturity, besides giving higher yields of sugar or *gul* will also contribute to the agricultural economy, as less plant food is then removed.

The data clearly prove that cane plants absorb the principal nutrient elements in widely different amounts, potash being taken up to the greatest extent and phosphate the least. The uptake of nitrogen and calcium is intermediate, that of the former being slightly higher than that of the latter. Further the rate at which several nutrients are absorbed varies with the age of the plant but not always in the same degree for each nutrient. This would be clear if one assumed the optimum uptake to be 100 and calculated the uptake at earlier stages on the basis of it. It would be then seen that the

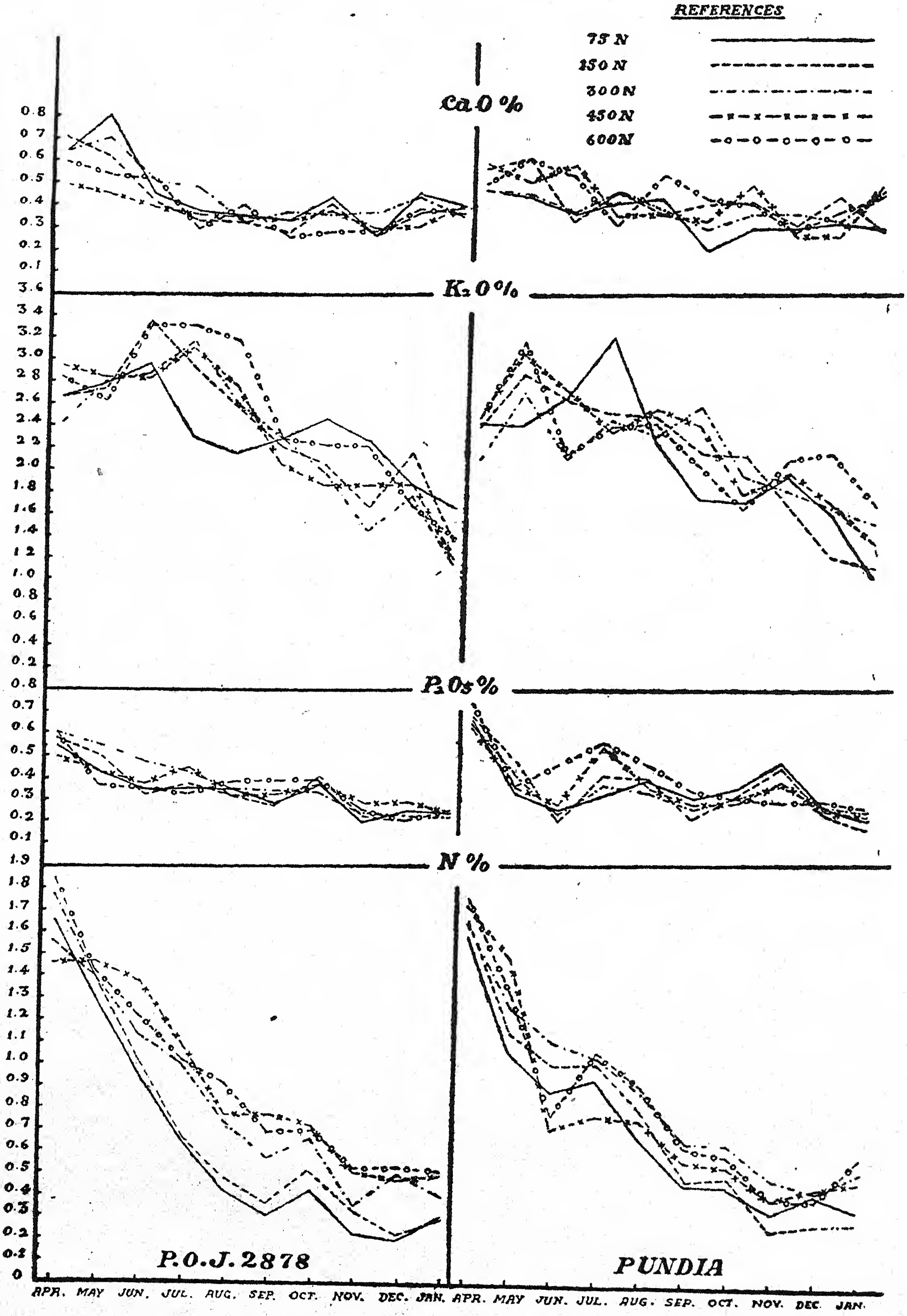

FIG. 2. Uptake per 100 gm. of plant material (Oven dry basis)—1935-36

rate of uptake is highest in the case of nitrogen closely followed by that of potash, while it is the least in the case of phosphate. Thus taking the figure at earthing up which is generally done after about six months from planting, the uptake of nitrogen and potash during this period has been about 40 to 50 per cent of the optimum, depending upon the treatments, while

TABLE IX

Water content

Treatment and variety	Functioning leaf: Water / Leaf area — Formative stage	Functioning leaf: Water / Leaf area — Grand period stage	Functioning leaf: Water / Leaf area — Maturity stage	Functioning leaf: Water / Dry weight — Formative stage	Functioning leaf: Water / Dry weight — Grand period stage	Functioning leaf: Water / Dry weight — Maturity stage	Stem: Water / Dry weight — Formative stage	Stem: Water / Dry weight — Grand period stage	Stem: Water / Dry weight — Maturity stage
POJ 2878—									
75 lb. N	0·31	0·38	0·33	3·3	2·6	1·6	7·3	4·5	2·6
150 lb. N	0·29	0·38	0·34	3·6	2·7	1·8	9·7	4·8	2·5
300 lb. N	0·30	0·39	0·34	3·2	3·3	2·1	9·6	5·3	2·9
450 lb. N	0·35	0·42	0·35	3·4	3·2	2·3	12·4	5·8	3·2
600 lb. N	0·31	0·45	0·38	3·6	3·3	2·5	15·8	6·4	3·4
Average	0·31	0·40	0·35	3·4	3·0	2·1	11·0	5·4	2·9
C. D. between any two treatments	0·120	0·026	0·106	0·970	0·49	0·47	...	0·79	0·75
Pundia—									
75 lb. N	0·32	0·43	0·30	3·5	3·1	2·2	11·0	5·4	3·6
150 lb. N	0·30	0·42	0·39	3·4	2·9	2·5	9·0	6·1	3·6
300 lb. N	0·33	0·42	0·38	3·3	3·5	3·0	9·4	7·7	4·4
450 lb. N	0·28	0·42	0·39	2·9	3·2	2·7	10·4	6·8	3·8
600 lb. N	0·33	0·39	0·37	4·1	3·2	3·1	9·1	7·5	4·3
Average	0·31	0·42	0·37	3·4	3·2	2·7	9·8	6·7	3·9
C. D. between any two treatments	0·106	0·078	0·099	0·69	0·49	0·69	...	1·98	1·26

TABLE X

Uptake of nutrients per acre in lb. 1935-36

Treatment and variety	Mid-May: N	Mid-May: P_2O_5	Mid-May: K_2O	Mid-May: CaO	Before earthing: N	Before earthing: P_2O_5	Before earthing: K_2O	Before earthing: CaO	Optimum: N	Optimum: P_2O_5	Optimum: K_2O	Optimum: CaO	Percentage of nitrogen utilized
1	2	3	4	5	6	7	8	9	10	11	12	13	14
POJ 2878—													
75 lb. N	31·9	10·1	68·3	19·4	33·1	12·1	99·2	15·8	87·7	57·1	365·0	75·2	116·9
150 lb. N	42·4	13·4	83·5	16·7	60·2	18·5	197·9	23·2	123·3	85·7	442·2	89·4	82·2
300 lb. N	32·6	8·2	82·6	16·7	57·4	9·5	137·1	25·2	227·2	121·5	580·9	177·3	75·7
450 lb. N	50·9	9·0	98·4	15·0	92·3	13·8	199·3	26·2	215·7	109·5	581·8	185·5	47·9
600 lb. N	42·3	11·1	78·5	15·7	77·3	21·5	217·5	23·0	213·0	112·8	697·1	119·4	35·5
Pundia—													
75 lb. N	25·7	8·4	58·0	10·6	34·0	9·5	102·5	15·1	79·7	71·2	364·1	93·6	106·3
150 lb. N	24·7	10·6	62·5	5·2	47·9	10·4	112·3	16·2	90·1	80·3	397·6	88·6	60·1
300 lb. N	27·7	9·1	59·9	10·1	31·9	12·5	104·6	18·0	151·2	114·3	531·9	134·5	56·4
450 lb. N	26·9	7·2	55·8	9·3	49·6	21·2	93·0	39·7	121·9	100·9	570·1	121·6	27·1
600 lb. N	22·7	6·3	52·1	10·3	29·2	17·1	92·2	20·4	132·8	89·3	408·0	113·5	22·1

that of phosphate about 15 to 20 per cent only. It will also be interesting to note that the major uptake of all the constituents takes place within three to four months after earthing up which coincides with the grand period of growth. Coming to the individual treatments the differentiation in the uptake of all the constituents is not so very evident till earthing up, i.e. up to six months, except in the case of 75 lb. N mainly in POJ 2878. This practically confirms the findings of Das [1936] who has stated that the uptake in either low, medium or high nitrogen series was the same up to about eight months when the differential effect of treatments began to manifest. In our experiments also it is only later that the differentiation is apparent and that also up to 300 lb. N the figures for higher nitrogenous series being practically similar to this treatment. In the case of Pundia there is in fact an indication of same deleterious effect on the uptake of these high nitrogenous doses. The application of a basal dressing of superphosphate at the rate of 100 lb. P_2O_5 during the next season has amended this by showing an increased uptake in these higher treatments over 300 lb. N with practically no difference in the figures for treatments up to 300 lb. N. Thus evidently while there could be a proper agrobiologic balance in the soil solution with nitrogenous top dressings up to 300 lb. N, quantities above this figure had created a disturbance in this balance.

In column 14 (Table X), the optimum uptake of nitrogen has been expressed as the percentage of the amount of N actually applied in top-dressings in different treatments. The figures are very instructive as they show that as the application of nitrogen increases the relative efficiency of its utilization decreases. Except in the lowest treatment of 75 lb. N, in which there has been actually a drain on the soil nitrogen, all other treatments have shown less uptake than the quantity of nitrogen applied. This has further varied according to the variety, Pundia being less efficient in this respect than POJ 2878. In the high N series as 450 and 600 lb. N, the percentage uptake specially in the case of Pundia is practically negligible. Even in 300 lb. N, about 44 per cent of nitrogen is not utilized in this variety, while in the case of POJ 2878 this figure comes to 25 per cent. It will be thus apparent that from the standpoint of the efficient absorption of nitrogen applied, POJ 2878 can take up higher nitrogenous dose than Pundia and that in higher nitrogenous series, much of the nitrogen so applied is not utilized by the crop. A part of it has remained no doubt in the soil and has given improved yields in the case of the rotational crop of cotton which followed the cane crop.

Minerals in cane juice and quality of gul. During 1935-36 the cane juice was periodically analysed from September onwards for mineral constituents as N. P, K, Ca, Mg and Na. In the case of N, amide N was also determined according to the method of Pucher [1935]. The data are given in Table XI. In order to reduce the size of the table, figures for the last three constituents are omitted from the table, as they did not show any variation between the treatments. From the juice obtained in the month of January, *gul* was prepared and it was similarly analysed. From the figures so obtained, the percentage constituents of the juice retained in the *gul* were calculated. The quality of this *gul* was also determined by tintometer colour standards. All these data are also included in Table XI.

These figures in combination with those for the purity of juice given in Table VII will show that the concentration of the mineral constituents in juice increases with the progress of maturity. It seems that there is a rapid translocation of them from the leaves to stems, once the growth is completed. In the case of nitrogen, simultaneously with its increased concentration there is a fall in the soluble nitrogen, which indicates synthesis of proteins. Coming to the individual treatments, there is an increase in total nitrogen with consequent increase in soluble nitrogenous compounds with the graduated nitrogenous doses. The reverse is, however, the case with phosphate, while potash seems to be practically similar in all the treatments during most of the periods. Among the varieties, *Pundia* shows a much lower concentration of all these mineral constituents than POJ 2878. Further, the ratio of N/P_2O_5 is approximately one in this variety as against two in the other case. Similarly the ratio of N/K_2O is lower in Pundia. Among the treatments the ratios, specially of N/P_2O_5 widen with increased nitrogenous manuring. The analyses of *gul* show that a higher percentage of nitrogen is removed by precipitation during the process of manufacture of *gul* in the case of Pundia than in POJ 2878 in which specially the *gul* from the higher nitrogenous treatments retains a greater proportion of nitrogen. On the other hand in these higher treatments, there is a greater loss of glucose which may be due to the destructive action of alkali salts. It is still a moot point, however as to how far these reactions are responsible for the quality of *gul*

TABLE XI

Per cent mineral constituents in juice and gul *1935-36*

Treatment and variety	N			P_2O_5			K_2O			Amide N Percentage of total N			Per cent constituents retained in *gul* from juice					Colour ratios $\frac{\text{yellow}}{\text{red}}$
	Sept.	Nov.	Jan.	Sept.	Nov.	Jan.	Sept.	Nov.	Jan.	Sept.	Nov.	Jan.	Total N	P_2O_5	K_2O	Amide N	Glucose	
POJ 2878—																		
75 lb. N	·0079	·0065	·016	·0225	·0155	·0173	·209	·236	·270	5·4	8·2	9·1	56·4	76·0	38·3	13·3	82·8	3·4
150 lb. N	·0136	·0085	·024	·0130	·0131	·0181	·258	·284	·300	7·1	7·6	8·3	51·5	84·0	39·1	19·1	74·9	3·1
300 lb. N	·0210	·0161	·023	·0094	·0079	·0139	·175	·219	·252	17·1	9·4	8·7	86·9	85·8	80·1	11·7	62·9	2·6
450 lb. N	·0369	·0370	·049	·0095	·0128	·0159	·187	·242	·291	19·9	14·3	13·9	75·2	80·5	78·3	8·3	56·8	2·1
600 lb. N	·0395	·0290	·069	·0071	·0141	·0149	·150	·248	·235	21·7	23·1	14·5	84·3	59·0	88·8	14·1	52·9	2·2
Pundia—																		
75 lb. N	·0076	·0049	·0099	·0094	·0136	·0158	·197	·161	·152	...	11·0	5·2	45·2	89·8	82·3	18·1	77·7	4·0
150 lb. N	·0075	·0073	·0083	·0146	·0158	·0153	·150	·169	·150	10·9	8·2	6·5	70·6	77·4	91·6	18·8	50·0	3·9
300 lb. N	·0082	·0129	·0189	·0094	·0128	·0125	·142	·153	·200	16·0	13·0	12·3	53·3	77·1	80·5	8·7	60·6	3·9
450 lb. N	·0260	·0137	·0208	·0144	·0122	·0116	·137	·150	·176	16·8	26·4	13·0	55·8	62·9	85·1	9·4	28·8	3·2
600 lb. N	·0240	·0280	·0307	·0113	·0145	·0120	·133	·178	·216	21·0	13·9	15·0	49·0	56·3	66·9	9·7	36·3	3·2

as judged by its colour. According to the market standard yellow colour fetches a greater price and the higher ratio of yellow to red thus indicates a better quality. A close relationship of the ratio of N/P_2O_5 in the juice from the different treatments and the colour standards of *gul* obtained from it is, however, visible. That the presence of phosphate improves the colour of *gul* is further confirmed by a practical method of addition of superphosphate to low-quality juice just before the striking point of *gul* in order to secure this yellow colour.

Availability of nutrients. This has been estimated in the case of nitrogen only by the analysis of soil for nitrates. This method was generally followed till the formation of cane when the exudation method of Weller [1931] was adopted in order to determine the availability of N as well as the other two nutrients of P and K. In order to secure the exudate, all the canes of the stool are cut and connected with a sterile flask with sterile tubes and the exudate so obtained from four such stools were analysed, for these three constituents by the colorimetric method of Steenkamp [1934]. Soil nitrates have in general shown a higher gradient with higher nitrogenous treatments with its accumulation in the balk. It is thus evident that nitrates thus formed are not all utilized by the crop during this period. The exudation studies (Fig. 3) have further revealed that POJ 2878 is capable of securing higher quantity of mineral nutrients than Pundia except in the case of P_2O_5. This can be ascribed to the differences in the root system of the two varieties already described by Rege and Wagle [1941]. Owing to the greater depth of root penetration POJ 2878 is able to tap lower soil depths. Similarly the thin profusely branching root system has been of advantage to Pundia in the case of P_2O_5 which would be more available in the surface soil layers owing to the basal application of superphosphate to all the treatments during this season. In the absence of similar analysis during previous years, when phosphatic manuring was not resorted to, it is very difficult to say whether normally Pundia would have shown a higher availability of P_2O_5 as observed during this season. Coming to the individual treatments, the availability of all these nutrients is at its maximum between June and August in the case of POJ 2878 and a month later in Pundia. In the treatments above 300 lb. N, these nutrients continue to be available even much later. While the rise in the availability of nitric N, between June and August is explicable by the dose of nitrogenous top-dressing applied in June at the time of earthing, similar rise in the case of P_2O_5 and K_2O indicates mainly the period required by these constituents in the soil to become available although there may be some contribution from the oilcakes applied in top-dressings. This maximum availability of all these nutrients closely corresponds with the grand period phase of the plant growth when the major absorption by the plant takes place. These findings may explain the reason why the standard chemical and plant methods

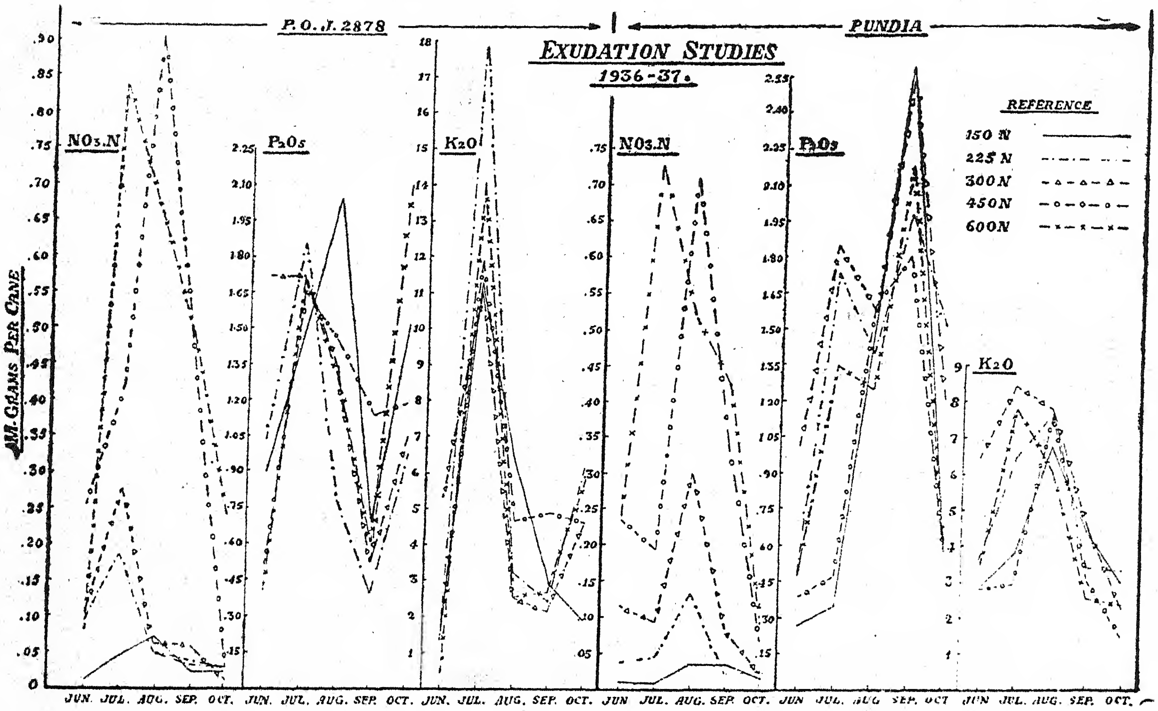

FIG. 3. Exudation studies—1936-37

for determining available P_2O_5 do not always give consistent results about the phosphatic status of the soil in the case of such a long-term crop as sugarcane. The exudation studies have also revealed the cause of the variation in the ratios of N to other constituents in the plant in the different treatments. It will be seen that while curves for P_2O_5 and K_2O are similar in the case of all the treatments, there is a big difference in the case of N with a definite gradient according to the treatments. Thus a higher quantity of P_2O_5 or K_2O will be available for absorption per unit N in the case of lower nitrogenous series than in the higher ones.

SUMMARY AND CONCLUSIONS

The problem of the nitrogen fertilization of sugarcane is of extreme importance in the Deccan Canal Tract, as the cultivation of the crop involves a large expenditure on nitrogenous top-dressings alone. In the present research work on January-planted cane, the treatments varied from 75 to 600 lb. N in graduated doses and the paper embodies the results of these treatments on the development of the plant, sucrose formation and mineral uptake which are summarized below:

(1) Practically all the plant phases are favourably influenced by nitrogenous manuring. In the case of germination an application of quick acting fertilizer as sulphate of ammonia is effective, the minimum dose for securing optimum germination being 15 lb. N at the time of planting. Increasing this dose even up to 60 lb. N has been of no further advantage.

(2) The tillering capacity is dominated by the concentration of nitrogen in the soil solution, as both low as well as high concentration affects this phase adversely the first by lowering its activity and the second by increasing it to abnormal proportions. The higher limit also differs for the varieties, POJ 2878 standing a higher concentration than Pundia among the two varieties under study. A nitrogenous dose supplying between 50 and 100 lb. available N is found to be the optimum one for this phase.

(3) Although the relative growth rate is practically similar in all the treatments except in the case of the lowest dose of 75 lb. N, it is in the continuation of growth that the effect of increasing applications of nitrogen is visible. The differentiation between the treatments appears after about eight months when the growth in the lower nitrogenous series practically ceases.

(4) Nitrogen favours increase in the number of functioning leaves as well as the length and width of the leaf. Although there is no signi-

ficant increase in the rate of carbon assimilation with increased nitrogenous doses the total synthesis of carbohydrates are expected to be higher owing to increased leaf area. Further nitrogen promotes succulence in cane, i.e. there is more water per gram of dry matter. The optimum limit of nitrogen for all these beneficial physiological characteristics appears to be 300 lb. N, higher nitrogenous doses showing in most cases insignificant variation from this treatment.

(5) Estimation of the relative contribution to the total cane tonnages has shown that the first order stalks contribute only 30 to 35 per cent in the case of POJ 2878 and 15 to 20 per cent in Pundia, the rest being practically made up by the tillers formed in April and May. It has been further observed from the weight of the individual canes that generally the growth of the first order stalks is poorer than that of April-formed tillers. In higher nitrogenous series similar results are also obtained in May-formed tillers in the case of Pundia.

(6) Increasing application of nitrogen increases the cane tonnages but decreases the concentration of sucrose in the expressed juice. It is observed that owing to short period of climate favourable to sucrose formation, delaying of harvest does not help in the formation of maximum sucrose in higher manuring. The commercial cane sugar per acre is a good criterion for fixing the limits of nitrogenous top-dressings which, however, vary according to the inherent characteristic of sucrose development. Thus, while in the case of early maturing variety as POJ 2878 one can go up to 600 lb. N, this last dose of nitrogen is definitely deleterious in the case of late maturing variety as Pundia. Similar will be the result with Co. 419 which is the leading cane in the Deccan Canal Tract as it is also a late-maturing variety. On economic considerations 300 lb. N, seems to be the optimum dose for the January planting in the case of all the varieties.

(7) Calculation of the water content of the leaf, both on dry weight basis and on leaf area, has given contradictory results owing to the increase in dry weight per unit leaf area with advancing age. From the standpoint of the physiological processes the latter method of calculation is found to be more suitable than the former.

(8) Studies in the mineral uptake have shown the differentiation in the percentage uptake only in the case of nitrogen which is very clear at later stages of grand period and at the maturity stage. The percentage uptake of other nutrients is practically similar for all treatments, and this creates an unbalanced nutrition resulting in continued growth and low sucrose formation in higher nitrogenous doses. The figures for uptake per acre have shown that the optiumn uptake of all these constituents is completed between October and December depending upon the treatments. Out of this, about 40 to 50 per cent in the case of N and K_2O and 15 to 20 per cent of P_2O_5 and CaO are taken up during the first six months, i.e. before earthing up. These findings are of greater importance in the evolution of an efficient system of manuring. As the cane attains maturity all the constituents shown a fall and this shows that harvesting the crop at its maximum maturity besides giving higher yields of sugar or *gul* will also contribute to greater economy as less plant food is removed. Among the principal elements potash is taken up to the greatest extent and phosphates the least, the uptake of nitrogen and calcium being intermediate. Estimation of the per cent uptake from nitrogenous top dressing has shown a decrease with increasing doses, Pundia being the least efficient in this respect.

(9) The concentration of the mineral constituents in the expressed juice increases with the progress of maturity as a result of the rapid translocation of these from the leaves to stem, once the growth is completed. With increasing application of nitrogen there is an increase in total as well as soluble nitrogen and decrease in the phosphate content. Among the varieties, Pundia shows a much lower concentration of all these mineral constituents in the juice with a lower ratio of N/P_2O_5. The good coloured *gul* obtained in this variety appears to be due to this.

(10) Availability of nutrients has been studied both by periodical soil analysis for nitrates and exudation studies for all the major nutrients. The latter method has revealed that POJ 2878 is capable of obtaining higher quantity of mineral nutrients than Pundia owing to the greater depth of the root penetration. The availability of all the nutrients is at its maximum during June to August in the case of POJ 2878 and a month later in Pundia. While this maximum availability of nitrogen is explicable by the big dose of nitrogenous top-dressing which the crop receives in June at the time of earthing up, such a late availability in the case of the other constituents indicates the time required by these soil constituents to come into soil solution, although there may be some contribution from the oil cakes applied at the time of earthing. This time coincides with the major uptake of all its nutriment by the plant and

this seems to be the reason why the standard chemical and plant methods for determining available P_2O_5 do not always give consistent results about the phosphatic status of the soil in the case of such a long-term crop as sugarcane.

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STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

X. THE INTERRELATION OF SOWING-DATE, NITROGEN, WATER-SUPPLY AND SPACING ON GROWTH AND YIELD OF 4-F COTTON*

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The results discussed in the preceding contribution [Dastur and Mukhtar Singh, 1943] showed that nitrogen was the determining factor for growth and yield of the cotton crop on light sandy soils, and water supply was of secondary importance. But, when the level of fertility was high, water supply also became a limiting factor. Consequently, the best development and the maximum yields were obtained when levels of both of these factors were simultaneously raised.

Applications of sulphate of ammonia as a general ameliorative measure for *tirak* caused by nitrogen deficiency involves a practical difficulty. Light sandy soils are interspersed with those possessing alkaline or saline subsoil. While the former respond so well to nitrogen, the latter are insensitive to its use. The magnitude of response in a particular field would, therefore, depend upon the relative distribution of the two soil types, other conditions being constant. Consequently, the problem of manuring is rendered complicated.

One of the methods of approach to meet this situation was to devise alternative ways for raising crop yields without recourse to artificial applications. The most practical way of accomplishing this was conceived to be delayed sowing. This aimed at economic utilization of the available nitrogen and water by reducing the plant size.

Deficiency of nitrogen and consequently *tirak* may well be minimized by delayed sowing but it may also lower the yields by reducing the size of the plants, since yield depends on the plants' scaffolding as well. Thus what may be gained in boll size may be lost in boll number and at times the loss might even exceed the gain. It was, therefore, necessary to examine the problem of spacing in relation to sowing date.

The foregoing considerations necessitated the introduction of sowing date and spacing factors in addition to nitrogen and water, in the 1939-40 experiment. Phosphorus and potash were omitted as they did not produce appreciable increases in yield in any of the previous experiments.

There is lack of published data on the interrelation of above-mentioned factors for the Punjab or India. This type of work has, however, been done in the Sudan in recent years with useful

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results [Gregory *et al.* 1932; Lambert and Crowther, 1935]. Additional features of the studies presented here are that they are supported by developmental data and have been made in relation to the soil conditions.

Description of the experiment

This experiment was conducted on light sandy soil in the rotation—wheat—*toria*—cotton. The treatments were all combinations of:

Factors	Sowing date		Nitrogen		Water		Spacing
Levels	d_1 = 12/5/39, d_2 = 2/6/39, d_3 = 22/6/39	×	o = Control, n = 50 lb. N. per acre on 14/8/39	×	w_1 = Normal wtgs., w_2 = Heavy wtgs. from mid-August	×	s_1 = 2 ft. × $1\frac{1}{2}$ ft., s_2 = $2\frac{1}{2}$ ft. × $2\frac{1}{2}$ ft.

It was necessary to reduce the block size by confounding. A balanced arrangement in six 12-plot blocks, as developed by Yates [1937], was adopted.

The plot size at sowing was $32\frac{1}{2}$ ft. × $60\frac{1}{2}$ ft. = 1/22·1 acre, accommodating 16 rows in S_1 and 13 in S_2 plots. The size of the plot for yield was 14 ft. × 48 ft. = 1/64·8 acre and $12\frac{1}{2}$ ft. × $47\frac{1}{2}$ ft. = 1/81·5 acre in S_1 and S_2 plots, respectively. Part of the plot area at borders was rejected as non-experimental and the rest utilized for dry-weight sampling.

It may be noted that sowings were spaced at an interval of 20 days. Plots designated as $d1$, $d2$ and $d3$ received 7, 6 and 5 irrigations respectively. The first irrigation was applied in the 5th week after sowing in all cases. Subsequent waterings were given at intervals of 20 days approximately for uniformity of conditions and agricultural convenience. This plan enabled the irrigation for the different sowings to fall on the same day.

General observations. The season 1939-40 was characterized by a long spell of heat and will be remembered for its dryness. But there were no visible symptoms of abnormal desiccation on the plants even under normal conditions of watering on this type of soil. The plants began to turn yellow even before the middle of August. Nitrogen application revived them in colour, freshness and lustre after a week, and slowly and gradually expressed itself in growth. The condition of the unmanured plants went from bad to worse. Even the fruiting parts were chlorotic. Late-sown plots were darker and greener when compared with the early-sown at the same stages of morphological development, and so were the widely-spaced plants in comparison to the thickly-spaced ones.

Experimental results

A great deal of developmental data at periodic intervals were collected. The values at the final stage and the aggregate yields were subjected to statistical analysis appropriate to the design. Table I shows at a glance the significant effects in case of the yield and the different vegetative and the reproductive characters.

The main effects of all the four factors on the different characters are significant, except those of water on flower production, boll number and node number, and of spacing on boll weight and yield. Of the first-order interactions those involving watering are not significant and all others, viz. sowing date × spacing, sowing date × nitrogen and spacing × nitrogen, merit consideration as they appear significant, in one form or the other, in the development of the plant. Of the high-order interactions, D×S×N alone deserves a reference.

All the main effects and the significant interactions on the basis of the statistical analysis have been presented in the form of summary tables, for the vegetative characters and the reproductive characters. Main differences with the corresponding standard errors are also given. Significance of the differences is indicated by asterisks as usual.

Dates. The dates have influenced significantly the entire plant development (Table II). The nature of responses, however, is dissimilar for the different characters. As the three sowings were equally spaced, the two comparisons corresponding to dates have been split up into the linear and the quadratic responses. The linear measures the response to 40 days' delay in sowing and is given by $d3$—$d1$. The quadratic is a measure of curvature or deviation of the behaviour of the central sowing from the linear trend, and is given by d_3-$2d_2$+d_1.

In the case of height the linear component is significant. The plant height decreases with delay in sowing but the decline is not progressive. The linear behaviour is conditioned and the quadratic response comes out significant.

The quadratic component is again significantly revealed in case of internodal length since the central sowing has given the longest internodes, the extreme sowings giving equal. Node production falls off successively from the first to the last sowing but not proportionately. The decrease is more rapid after the second sowing. In case of dry weight per plant or per square yard as well as flower production, the decline with delay in sowing is definitely linear and the quadratic component is suppressed.

The direction of effect on the setting percentages is the reverse of that on flower production. The percentage of flowers maturing into bolls

TABLE I

'F' values of the significant effects for the vegetative and the reproductive characters

Due to	D. F.	Height	No. of nodes	Internodal length	Dry wt. per plant	Flowers	Boll number	Boll weight	Yield of *kapas*
D'1	1	45·63**	188·5**	...	230·8**	221·5**	15·79**	13·80**	5·95*
D11	1	29·97**	6·8*	28·99**	...	...	3·97	...	8·81**
N	1	92·53**	81·9**	43·36**	156·4**	130·6**	75·2**	35·11**	159·74**
W	1	11·65**	...	7·88**	6·27*	...	...	5·38*	4·01*
S	1	41·42**	67·1**	10·42**	142·61**	26·3**	9·9**	...	...
D × N	2	...	...	...	18·31**	7·44**	2·59	7·42**	7·50**
D × W	2	...	...	...	...	...	...	...	...
D × S	2	7·39**	8·4**	4·19*	12·31**	...	5·56**	...	...
N × W	1	...	...	...	...	...	...	...	...
N × S	1	5·38*	...	8·65**	...	5·84*	...	5·73*	6·33*
W × S	1	...	...	...	10·51**	...	...	...	...
D × N × W	2	...	...	...	...	...	...	...	...
D × N × S	2	...	...	...	...	...	3·56*	...	...
D × W × S	2	...	...	...	...	...	...	...	...
N × W × S	1	...	...	...	...	...	...	...	...
D × N × W × S	2	...	...	...	...	...	...	...	...

* = Significant at 5 per cent level ** = Significant at 1 per cent level

TABLE II

Main effects of sowing date on the vegetative and the reproductive characters

	Height (cm.)	No. of nodes	Inter-nodal length (cm.)	Dry wt. per plant (gm.)	Dry wt. per sq. yard (gm.)	Flowers per sq. yard	Setting percent-age	Bolls per sq. yd.	Seed cotton per boll	Yield in md. per acre
d_1	81·9	35·7	2·28	237	482	261	25·5	55·1	1·365	11·17
d_2	84·1	34·2	2·45	181	370	203	29·4	54·5	1·515	12·01
d_3	71·0	31·2	2·27	118	248	132	36·3	45·4	1·573	9·66
D1	*—10·94***	*—4·52***	*—0·006*	*—118·9***	*—233·8***	*—128·8***	*+10·83***	*—9·68***	*+0·208***	*—1·51**
D11	*—15·36***	*—1·48**	*—0·354***	*—06·8*	*—9·8*	*—13·4*	*+2·95*	*—8·42*	—0·*092*	*—3·19***
S. E. (11)(for D1)	±1·62	±0·33	±0·038	±7·8	±20·2	±8·65	±1·06	±2·44	±0·056	±0·601
S. E. (2) (for D11)	±2·80	±0·57	±0·066	±13·6	±35·0	±14·99	±1·84	±4·22	±0·096	±1·043

increases steadily as the sowing date advances. Higher setting percentages in the later sowings have improved their status so far as boll numbers are concerned. This is why, the decrease in boll number is inappreciable from the first to the second sowing, nevertheless the reduction is still substantial in the third sowing. Thus the compensation has been inadequate in case of the last sowing The quadratic response to dates on boll-number is, therefore, on the verge of significance.

As in the case of setting percentage, the linear response to dates on boll size is positive and significant. The gradual increase in boll size with delay in sowing have affected the yield performance of the sowing dates. The second sowing has given the maximum yield. However, the yield in the third sowing in spite of the maximum boll weight continues to be lower than the first two sowings. The reason for this decline in yield will be clear later when the interactions of dates with spacing and nitrogen are considered.

Nitrogen. The dominating influence of nitrogen on growth, amelioration of *tirak*, and improvement in yield is clearly established by the results of this experiment (Table III). The evidence obtained fully confirms the previous findings [Dastur and Singh, 1943] and needs no further elaboration. It is, also noteworthy that the setting percentage is unaffected by nitrogen.

TABLE III

Main effects of nitrogen on the vegetative and the reproductive characters

	Height (cm.)	No. of nodes	Inter-nodal length (cm.)	Dry wt. per plant (gm.)	Dry wt. per sq. yard (gm.)	Flowers per sq. yard	Setting percent-age	Bolls per sq. yd.	Seed cotton per boll	Yield in md. per acre
o	72·7	32·4	2·23	139	279	158·1	30·41	43·04	1·349	7·95
n	85·4	34·9	2·44	219	455	238·9	30·34	60·29	1·620	13·95
Diff.	** *+12·72*	** *+2·43*	** *+0·204*	** *+79·9*	** *+175·3*	** *+80·8*	*—0·07*	** *+17·25*	* *+0·271*	** *+6·00*
S. E.d. . . .	±1·32	±0·27	±0·031	±6·4	±16·5	±7·07	±0·87	±1·99	±0·045	±0·491

Watering. Heavy watering has neither affected the production of flowers nor of bolls but it has increased significantly the height through elongation of internodes and the yield through improvement in boll size (Table IV). The magnitude of increase in yield is, however, very small but as none of the interactions of watering have come out significant, this small increase is consistently obtained at all levels of the other factors.

TABLE IV

Effect of water on the vegetative and the reproductive characters

	Height (cm.)	No. of nodes	Inter-nodal length (cm.)	Dry wt. per plant (gm.)	Dry wt. per sq. yard (gm.)	Flowers per sq. yard	Setting percent-age	Bolls per sq. yd.	Seed cotton per boll (gm.)	Yield in md. per acre
w_1	76·8	33·4	2·29	171	357	203·6	31·13	51·51	1·431	10·44
w_2	81·3	33·9	2·38	187	377	193·5	29·62	51·82	1·537	11·45
Diff.	** *+4·51*	*+0·47*	** *+0·087*	* *+16·0*	*+19·3*	*—10·1*	*—1·51*	*+0·31*	* *+0·106*	* *+1·01*
S. E.d . . .	±1·32	±0·27	±0·031	±6·4	±16·5	±7·07	±0·87	±1·99	±0·045	±0·491

Spacing. When the plants are widely spaced the growth in extension as well as dry matter per plant is significantly greater than when spaced closely (Table V). This is to be expected as, plant for plant, greater resources, e.g. light, nutrients, water, etc., are at the disposal of individuals. When the production of dry matter is considered on the area basis, the reverse condition obtains. The compensatory growth due to wide spacing does not adequately cover the loss of plant number. The same relation holds in case of flowers or boll production per square yard. There is, also, suggestive increase in yield under close spacing.

TABLE V

The main effect of spacing on the vegetative and the reproductive characters

	Height (cm.)	No. of nodes	Inter-nodal length (cm.)	Dry wt. per plant (gm.)	Dry wt. per sq. yard (gm.)	Flowers per sq. yard	Setting percent-age	Bolls per sq. yard	Seed cotton per boll	Yield in md. per acre
s_1	74·8	32·6	2·29	141	422	216·7	30·28	54·79	1·486	11·31
s_2	83·3	34·8	2·39	217	312	180·4	30·47	48·53	1·483	10·58
Diff.	** *+8·51*	** *+2·20*	** *+0·100*	** *+76·3*	** *—109·9*	** *—36·3*	*+0·19*	** *—6·26*	*—0·003*	*—0·73*
S. E.d. . . .	±1·32	±0·27	±0·031	±6·4	±16·5	±7·07	±0·87	±1·99	±0·045	±0·491

The main effects discussed above are averaged over all levels of the remaining factors. When the effects vary with the change in the level of the other factors, the main effects are misleading if no reference is made to the interactions. It is, therefore, necessary to study the differential responses by two-way tables.

Sowing date and nitrogen. The effect of nitrogen on height, node number and internodal length under the three sowings individually shows that the responses are all highly significant and are virtually similar under the different sowings (Table VI). There is thus little evidence of differential behaviour on any of these characters.

TABLE VI

Interaction : sowing date and nitrogen

Height (cm.)				Node number				Internodal length (cm.)			
	d_1	d_2	d_3		d_1	d_2	d_3		d_1	d_2	d_3
o	75·0	77·0	66·0	o	34·5	32·7	30·1	o	2·17	2·35	2·19
n	88·8	91·3	76·0	n	36·8	35·6	32·2	n	2·40	2·56	2·36
diff. ±2·29 . .	** *+13·8*	** *+14·3*	** *+10·0*	diff. ±0·465 .	** *+2·3*	** *+2·9*	** *+2·1*	diff. ±0·054 .	** *+0·23*	** *+0·21*	** *+0·17*

The case with growth as measured by dry weight per plant or per square yard is different (Table VII a & b). Though increase due to nitrogen is substantial and highly significant in all sowings, the response to nitrogen shows a progressive and proportionate decline with each deferred sowing.

TABLE VII

Interaction : Sowing date and nitrogen

(a) Dry wt. per plant (gm.)				(b) Dry wt. per sq. yd.				(c) Flowers per sq. yard			
	d_1	d_2	d_3		d_1	d_2	d_3		d_1	d_2	d_3
o	173	142	102	o	345	281	212	o	211	153	111
n	301	220	135	n	619	460	285	n	310	253	153
Diff. ±11·07 .	** *+128*	** *+78*	** *+33*	Diff. ±28·6 .	** *+274*	** *+179*	* *+73*	Diff. ±12·2 .	** *+99*	** *+100*	** *+42*
(d) Bolls per sq. yard				(e) Seed cotton per boll (gm.)				(f) Yield of seed cotton md. per acre			
	d_1	d_2	d_3		d_1	d_2	d_3		d_1	d_2	d_3
o	45·6	43·6	39·9	o	1·125	1·375	1·548	o	7·25	8·57	9·02
n	64·6	65·3	51·0	n	1·605	1·655	1·599	n	15·10	15·45	11·31
Diff. ±3·44 .	** *+19·0*	** *+21·7*	** *+11·1*	Diff. ±0·079 .	** *+0·480*	** *+0·280*	*+0·051*	Diff. ±0·85 .	** *+7·85*	** *+6·88*	** *+3·29*

These relations can be understood in terms of growth behaviour of the three sowings. Mention has already been made of the decreasing dry weights at the final stage, as the sowings are delayed. Early sowing has the advantage of time for the production of larger scaffolding before the N-application made in August begins to take effect. Correlated with this are the signs of internal starvation. Both of these conditions increase potentialities of the early sowings for further increase in dry matter through nitrogen applications. These pre-requisities are wanting in the late sowing and their absence renders them less responsive to nitrogen. It is interesting to note that similar interaction effect has not come out significant in the case of height. Height measures the growth of the apical meristem of the main axis only. There are similar growing points all over the plant, and it can be inferred, from the absence of D×N interaction in case of height, that each of them will grow with nitrogen to the same extent irrespective of the time of sowing. But the number of points to elongate and thicken are more in the case of early sowings, so the increase due to nitrogen in the total dry matter is also greater. Less and less points are benefited in case of later sowings and the response is correspondingly low. So the effects on height and dry weight, though apparently different, prove essentially the same phenomenon.

The differential responses to nitrogen in yield with shifts in sowing dates can be followed up step by step from the data presented in Table VIII(c-f). The three sowings have not behaved alike in their responses to nitrogen in flowering. The first two have profited equally and the magnitude of increase in the third is much lower.

Similar effect is noticeable in case of boll number.

The improvement in boll weights with nitrogen falls off progressively and proportionately as cotton is sown successively later. This is so because the boll size rises rapidly from the first to the last sowings in the absence of nitrogen, while application of nitrogen tends to maintain the boll weight at 1·60 gm. nearly in all the sowings. In the absence of nitrogen, *d3* is able to nourish

about as big a boll as any of the three sowings with nitrogen, and hence the last sowing is the least benefited by its application. It is thus clear that sowing date and nitrogen are identical in their effect in bringing about better maturity of bolls, and the effect of one is absorbed in that of the other. When two factors work in the same direction, the law of diminishing utility operates because some other factor becomes limiting.

The combined effect of treatments on boll number and boll weight appears in yields. The increase in the production of *kapas* (seed cotton) with nitrogen is less and less marked as sowings are shifted towards June but the fall is more rapid after the central sowing.

Sowing date and spacing. A study of the effect of spacing under the three sowings (Table VIII) reveals that the capacity for compensatory growth due to wide spacing varies with the date of sowing. The first two sowings tend to produce taller plants, more nodes, and longer internodes under wide spacing while the last sowing is scarcely affected by spacing. Between the first two sowings, strangely enough, the increase is greater in the second. This behaviour is associated with the greater increase in the length of the internodes, rather than their number, under the central sowing date as compared with the first.

The interaction, sowing date × spacing, is again highly significant on dry weight per plant (Table IX-a). The nature of effect is, however, slightly different. The increase in dry weight per plant by wide spacing falls progressively in the direction of late sowing and this result resembles, in all respects, the relation between sowing date and nitrogen. Thus reduction in plant number results in the operation of compensatory mechanism which becomes less and less efficient as sowing is delayed.

TABLE VIII

Interaction : sowing date and spacing

Height (cm.)				Node number				Internodal length (cm.)			
	d_1	d_2	d_3		d_1	d_2	d_3		d_1	d_2	d_3
s_1	77·1	77·1	70·1	s_1 . . .	34·3	32·6	30·8	s_1 . . .	2·23	2·35	2·28
s_2	86·8	91·2	71·9	s_2 . . .	37·1	35·7	31·5	s_2 . . .	2·33	2·56	2·27
Diff. ±2·29 .	** +9·7	** +14·1	+1·8	Diff. ±0·465	** +2·8	** +3·1	+0·7	Diff. ±0·054	+0·10	** +0·21	—0·01

TABLE IX

Interaction : sowing date and spacing

(a) Dry wt. per plant				(b) Dry wt. per sq. yard (gm.)			
	d_1	d_2	d_3		d_1	d_2	d_3
s_1	181	141	101	s_1	542	422	302
s_2	294	222	136	s_2	422	319	195
Diff. ±11·07 . .	** +113	** +81	** +35	Diff. ±28·6 . .	** —120	** —103	** —107

The failure of the internodes of the third sowing to elongate with wide spacing, even though dry weight increases, can be explained in terms of the operation of some other factors. There is freer movement of hot and dry air in widely-spaced plants of the last sowing and individual plants are subject to high insolation. The desiccation effects thus produced counteract the advantages of better supply of water and nutrients from below, and thereby limit extension growth of the main axis, but these potential resources attending wide spacing definitely contribute to increase the dry matter in the third sowing also though the increase is comparatively small.

When the results are expressed on area basis (Table IX-b), wide spacing gives significantly lower values than the close one and all decreases are of the same order under the three sowings. There is thus no interaction in case of total dry matter per square yard. Close spacing and early sowing are analogous in their behaviour with regard to the production of dry weight per unit area. Close spacing is capable of exploring the natural resources more efficiently than the wide one by virtue of the increased number of individuals, while early sowing has the advantage of time which enables extensive root growth and exposure to more hours of illuminations. Maximum dry

weight is produced under the earliest sowing with close spacing. Every delay in sowing by 20 days or the adoption of wide spacing lowers the output of dry matter by about 100 gm. till minimum is obtained under $d_3 s_2$.

Reference has already been made under main effects to the superiority of close spacing in raising the yield and the boll number. On further analysing the data, it is seen (Table X) that no special advantage has accrued to the first two sowings in regard to boll number and yields by close spacing. The third sowing alone has significantly profited by close spacing.

It has just been mentioned that consistently higher dry weights per square yard have been obtained in this experiment with close spacing as compared with the wide in all the sowings, while in case of reproductive development close spacing has benefited the third sowing only. This shows that surplus dry matter, beyond a certain maximum, is ineffective and plays no vital role in the economy of the plant. Wide spacing and late sowings produce plants which are, weight for weight, efficient for the production of *kapas*. The smaller the size of the plant the greater is its efficiency for the production of seed cotton (Table X-c). At the same time it may be pointed out that, though late-sown widely-spaced plants possess the maximum efficiency, compensation is inadequate under this treatment.

TABLE X

Interaction : sowing date and spacing

(a) Bolls per sq. yd.				(b) Yield (md. per acre)				(c) Seed cotton per 100 gm. of dry matter			
	d_1	d_2	d_3		d_1	d_2	d_3		d_1	d_2	d_3
s_1	56·2	54·9	53·2	s_1 . . .	11·22	12·20	10·53	s_1 . . .	13·65	19·53	23·46
s_2	54·0	54·0	37·6	s_2 . . .	11·13	·11·82	8·79	s_2 . . .	16·28	24·38	30·36
Diff ±3·44 .	—2·2	—0·9	** —15·6	Diff. ±0·85 .	—0·09	—0·38	** —1·74				

Thus below a certain minimum dry weight, gain in efficiency fails to cover the loss in yield caused by reduced bearing due to small size of the plants. This lower limit is indicated at about 325 gm. per square yard in the present case (Table IX-b).

The manner of adjustment, by which a small-sized plant tends to equal or excel in yield the one with larger structure, takes the form of modification in the relative distribution of total dry matter in parts as given in Table XI which is self-explanatory. The case of nitrogen, which raises the dry weight of the plants and still increases their efficiency, would seem paradoxical. The cause for this is to be sought in the nutritional disorder that nitrogen corrects.

Nitrogen and spacing. The results showing the interrelations of nitrogen and spacing are consolidated in Tables XII and XIII.

TABLE XI

Percentage distribution of total dry matter in parts

(Plants sampled on 28 October)

	$d_1 s_1$	$d_1 s_2$	$d_1 s_1 n$	$d_1 s_2 n$	$d_2 s_1$	$d_2 s_2$	$d_2 s_1 n$	$d_2 s_2 n$	$d_3 s_1$	$d_3 s_2$	$d_3 s_1 n$	$d_3 s_2 7n$
Stems	26·4	31·5	27·8	30·4	25·6	26·4	27·4	29·2	19·1	22·9	24·1	23·7
Leaves	13·1	15·8	16·7	18·4	14·6	15·6	16·3	21·7	15·1	20·7	20·9	25·1
Dead leaves . . .	38·7	28·5	30·9	22·8	38·4	31·1	30·1	22·5	37·4	25·4	28·2	19·8
Bolls	21·7	24·1	24·6	28·3	21·3	26·8	26·2	26·5	28·4	30·9	26·8	31·5

TABLE XII

Interaction : nitrogen and spacing

(a) Height (cm.)			(b) Internodal length (cm.)			(c) Dry weight per plant (gm.)			(d) Dry wt. per sq. yard (gm.)		
	s_1	s_2		s_1	s_2		s_1	s_2		s_1	s_2
o	66·9	78·4	*o* . . .	2·14	2·33	*o* . .	102	176	*o* . .	306	253
n	82·7	88·1	*n* . . .	2·43	2·44	*n* . .	179	258	*n* . .	538	372
Diff. ±1·87 .	** *+15·8*	** *+[illegible]·7*	Diff. ±0·044	** *+0·29*	** *+0·11*	Diff. ±9·04	** *+77*	** *+82*	Diff. ±23·3	** *+232*	** *+191*

It is apparent that nitrogen acts as a limiting factor in case of close spacing since minium values for all grow th measurements per plant are obtained under this treatment in the absence of nitrogen, and wide spacing or nitrogen stimulates elongation as well as the incorporation of dry matter. Of the two factors, 50 lb. N per acre seems to be more effective. There are further increases in height and dry matter when nitrogen is applied to widely-spaced plants. But, before considering the magnitude of such increases, it is necessary to bear in mind that s_2 plots contain less plants per unit area in comparison to those of s_1. As manure is applied at a uniform rate in lb. per acre the individual plant under wide spacing gets proportionately larger dose of manure as compared with an individual of close spacing. In spite of this privilege, widely-spaced plants derive only as much benefit in the production of dry matter from nitrogen application as the closely-spaced plants (Table XII-c). The effect is even more pronounced in case of height and internodal length where s_2 plants have distinctly responded less than the s_1 plants. There is thus a clear indication of diminished utility of nitrogen with wide spacing. This is further confirmed when the data for dry weight are considered on area basis (Table XII-d). The spacing (i.e., s^1) which produces greater dry matter in the absence of nitrogen is the most responsive to its application.

Essentially the same relations are seen to hold in case of yield and the yield characters (Table XIII). Although nitrogen affects bearing, boll development and yield significantly under either of the two spacings, the magnitude of response is distinctly heavier with the close spacing.

TABLE XIII

Interaction : nitrogen and spacing

Flowers per sq. yd.				Bolls per sq. yd.				Boll weight (gm.)				Yield (md. per acre)			
	s_1	s_2	Diff. ±9·99		s_1	s_2	Diff. ±2·81		s_1	s_2÷	Diff. +0·065		s_1	s_2÷	Diff. +0.694
o .	168	149	—19	*o* .	45·4	40·7	—4·7	*o* .	1·29	1·40	+0·11	*o* .	7·68	8·22	+0·54
n .	266	213	—53	*n* .	64·2	56·4	—7·8	*n* .	1·67	1·56	—0·11	*n* .	14·95	12·95	—2·01
Diff. ±9·99	** *+99*	** *+64*	...	Diff. ±2·81	** *+18·8*	** *+15·7*	...	Diff. ±0·065	** *+0·38*	* *+0·16*	...	Diff. ±0·694	** *+7·27*	** *+4·73*	...

The analysis can be carried a step further (Table XIV). The importnce of close spacing for the enhanced utilization of nitrogen in regard to the yield and the boll number is not general but is restricted to the two later sowings. This signifies the second order interaction D×S×N. Similar interaction effect is absent in the case of boll weight, for the effect of nitrogen is more pronounced under close than that under the wide spacing, irrespective of the sowing date.

TABLE XIV

Interrelation of dates, nitrogen and spacing

(*a*) Boll number				(*b*) Yield (md. per acre)				(*c*) Boll weight (gm.)			
	d_1	d_2	d_3		d_1	d_2	d_3		d_1	d_2	d_3
s_1	49·6	42·3	44·3	s_1	7·19	7·68	8·17	s_1 . . .	1·078	1·304	1·506
s_1n	*62·9*	*67·5*	*62·2*	s_1n . . .	*15·24*	*16·73*	*12·90*	s_1n . .	*1·662*	*1·737*	*1·627*
Diff.	13·3	25·2	17·9	Diff.	8·05	9·05	4·73	Diff.	0·584	0·433	0·121
s_2	41·6	44·9	35·5	s_2	7·31	9·47	7·87	s_2 . . .	1·173	1·445	1·590
s_2n	*66·3*	*63·1*	*39·7*	s_2d . . .	*14·95*	*14·17*	*9·72*	s_2n . .	*1·549*	*1·574*	*1·569*
Diff.	24·7	18·2	4·2	Diff.	7·64	4·70	1·85	Diff.	0·376	*0*·129	—*0*·071

It is clear from the data in Table XIV that the principle of fluctuating optimum finds its application to the problem of crop production. The results have, therefore, direct practical value. The adjustment in cultural conditions can safely be put forward on the basis of these results.

For want of space it is not proposed to give here even a concise account of the entire progressive growth data collected. It would be of interest all the same to consider the rate of flower production as affected by sowing date and nitrogen (Table XV).

Rates of flower production. Whereas the sowings were done at intervals of 20 days, the first flowering counts in the successive sowings were started with a delay of only half the period. In

TABLE XV

Rates of flowering per square yard (5-day totals)

Treatments	August		September						October				
	26-30	31-4	5-9	10-14	15-19	20-24	25-29	30-4	5-9	10-14	15-19	20-24	25-29
d_1	2·8	8·9	19·7	29·7	32·0	*35·8*	30·6	26·5	14·2	7·2	2·7	0·6	...
d_2	...	...	6·8	15·0	23·0	30·6	*31·2*	24·5	13·3	5·4	2·2	0·6	0·3
d_3	...	...	...	...	8·9	15·4	19·7	*25·2*	17·9	13·0	6·6	2·4	0·9
d_1n	3·9	7·4	19·2	35·1	40·9	51·2	*52·2*	50·5	31·9	16·5	3·1	0·6	...
d_2n	...	...	7·2	17·1	25·3	39·3	42·4	*51·7*	36·9	22·5	7·9	2·1	0·6
d_3n	...	...	...	...	7·4	14·5	20·1	*28·2*	26·6	25·6	16·8	7·2	5·8

fact there is a clear indication that flower counts in the two later sowings should have been started even earlier. It is the most significant point that flowering proceeds in the three sowings in quick succession both in the presence and the absence of nitrogen Furthermore, an initial postponement in sowing by 20 days causes a 5-day shift in the period of maximum flower production. The flowering in the two sowings ceases simultaneously. It is, however, true that 20 days' delay in sowing effects a substantial reduction in total bearing. This is so because the rate in the second sowing in comparison to the first remains at a low level throughout September and the difference is not made good later. When sowing is deferred by a further period of 20 days, the commencement of flowering is further shifted by about 10 days as compared with the central sowing. The peak and the cessation of flower production are also delayed but only by five days or so. The flower production during September continues at so low a rate in the last sowing that a less rapid fall in the fruiting activity during October does not compensate for the early diminution in the flowers. In short, late sowing does not mean equivalent delay in the onset of flowers and the maturity of bolls, as is commonly apprehended, but it does bring about reduction in bearing.

The effect of nitrogen on flower production is outstanding in all the sowings but it is apparent that the increases due to nitrogen in the first two sowings are recorded from 10 September and are continued to the end. On the other hand, the increase is confined to the month of October in the third sowing. This is why the response to nitrogen on bearing is comparatively low in the third sowing.

DISCUSSION

A delay in sowing by a given period shifts forth the commencement of flowering by 1/3 the interval between sowings, and the time of maximum flowering is still less affected. Thus all sowings do not enjoy equal period to grow vegetatively, before they come into bearing. The plant passes on to the reproductive phase as soon as the day length is shorter than the critical photoperiod, irrespective of the amount of vegetative growth it has made. As the appearance of flowers brings about the retardation and the ultimate cessation of vegetative activity the plants are incapacitated during fruiting to make good any loss in dry weight or the number of the nodes. Since the number of flowers are dependent on the growth already made by the plant, potential bearing suffers in the later sowing in proportion to the reduction in the vegetative growth.

Although the fall in the potential crop of flowers by deferred sowings is linear as a result of the reduction in dry weight, there are a set of counterbalancing tendencies working in the plant, which tend to keep up their yields. Any delay in sowing is accompanied by a simultaneous increase in the percentage success of flowers into bolls. In consequence thereof, the number of bolls finally matured in the second sowing equals that of the first. Of course the compensation in the last sowing, is inadequate to annul the disadvantage of reduced bearing even though the setting percentage is the maximum in this sowing.

There is a progressive increase in the weight of seed cotton produced per boll as cotton is sown successively later. The object of ameliorating *tirak* on light sandy soils is realized by delay in sowing, as boll weight is a composite measure of all round development of both seed and lint.

The cumulative effect of the above-mentioned characters, i.e. higher setting percentage and better boll weight, which offsets the reduction in flowers in the later sowing appears in the final yield of *kapas*. The efficiency of the plant as a producer of seed cotton per unit of dry matter gradually increases so that sowing date has an

optimal value around the central sowing. Besides, the third sowing excels the first by a small margin in the absence of nitrogen.

The ameliorative effect of late sowing on the opening of bolls on light sandy soils operates through the maintenance of adequate concentration of nitrogen within the plant (Table XVI) by cutting down the vegetative growth. Direct applications of nitrogen have likewise increased the percentage of nitrogen in the leaves at each stage of growth in the first sowing and correspondingly the boll size. Both these factors, late sowing and nitrogen manuring have independently increased the concentration of nitrogen as well as the size of the bolls. But the two factors, working in the same direction when combined do not contribute their individual shares in raising the boll size, even though their effects on the concentration of nitrogen are additive. It is remarkable that higher concentrations of nitrogen in the late-sown treated plants are not accompanied by any additional improvement in boll size which remains at about 1·6 gm. seed cotton per boll so that sowing date and nitrogen interact in case of boll weight. The inprovement in boll opening due to nitrogen falls progressively and proportionately with advancing sowing dates. The interaction is again reflected in yield in

TABLE XVI

Concentration of total nitrogen in the leaves. Percentage on dry weight (5-plant samples)

Control					50 lb. N applied on 14-8-39				
—	Dates of sampling				—	Dates of sampling			
	21/8	10/9	30/9	20/10		21/8	10/9	30/9	20/10
Sowing dates					Sowing dates—				
12-5-39 . . .	2·14	1·63	1·50	1·31	12-5-39 . . .	2·47	2·84	2·12	1·76
2-6-39 . . .	2·20	1·73	1·60	1·32	2-6-39 . .	2·67	3·04	2·52	2·11
22-6-39 . . .	2·98	2·39	1·97	1·81	22-6-39 . .	3·53	3·33	3·32	2·70

the form of diminishing responses to nitrogen with delayed sowings. The differential behaviour of nitrogen with the three sowings is also recorded in case of dry weight.

The interaction between gowing date and nitrogen is explicable in terms of the progressive changes in the concentration of nitrogen in leaves of the different treatments. Nitrogen applied to the first sowing is fully utilized and finds expression in increased growth of the vegetative and the reproductive parts. There is a clear evidence of luxury consumption in the late-sown treated plants which get only inadequately depleted in comparison to all the other series (Table XVI). The higher concentrations of nitrogen which are without effect result from the combined action of the two treatments analogous in their behaviour, and point to the operation of some limiting factor. It is suggested on the basis of the growth made by plants in the three sowings prior to flowering that carbohydrates become limiting in the late sowings. A balance between carbohydrates and nitrogen appears to be of fundamental importance for the proper maturation of bolls. In early sowing there is no shortage of carbohydrate supplies. This is to be expected under conditions of long cloudless days in the summer, which enable the early-sown plant to manufacture and store large reserves of carbohydrates. In fact there is conclusive evidence [Daster, 1939] that unless utilized, the primary products of photosynthesis accumulate as starch and finally appear as tanninlike substances, on N-deficient soils. Such a condition is corrected either by delaying the sowing date or by addition of nitrogen. The mode of its action has already been explained. However, when nitrogen is applied to the late sowing the scales turn over. Only a small proportion of nitrogen is made use of in the formation of bolls while the rest raises the internal concentration and remains without further effect. It is probable that harmful effects of nitrogen concentrations might set in beyond certain limits under such conditions of unbalanced nutrition.

Gregory *et al.* [1932] obtained similar interaction of sowing date with nitrogen in yield, and linked this behaviour to the prevalence of certain external factors, (1) the rate of nitrification in the soil, and (2) the effect of climatic conditions on the nitrogen uptake by the plants. The present investigation reveals that the explanation should account for the actual utilization of the absorbed nitrogen rather than the rate of its availability and uptake.

Another important finding of the experiment is the enhanced utilization of nitrogen with closer spacing. The differential behaviour of nitrogen with spacing is well pronounced on the vegetative as well as the reproductive characters. The relation between spacing and nitrogen is in accord

with observations made by Crowther *et al.* [1937]. The ultimate source of this interaction in case of yield is the boll weight component in the present case. Thus close spacing has functioned in the same manner as the early sowing in relation to nitrogen and this behaviour becomes intelligible in terms of the explanation offered for the interaction sowing date × nitrogen. In addition, the probability that widely spaced plants are less efficient in the adequate removal of nitrogen supplied, because of their less extensive root system, cannot be set aside.

Spacing has also interacted with sowing date. For the first two sowing it is immaterial whether spacing is close or wide within the limits tried but close spacing becomes indispensable for the last sowing for counteracting the depression in boll number.

The response to water is low. Moreover it has not interacted with any other factor. This is striking in view of the hot and dry weather during 1939 under which the experiment was conducted, not in keeping with the experience of Gregory *et al.* [1932]. It follows, therefore, that water does not normally become limiting on light sandy soils. The significance of this factor and the decline in its response under late sowing has been stressed on sandy loam soils with salinity in the subsoil [Dastur and Mukhtar Singh, 1942].

Further experiments

The main findings on the effect of nitrogenal sowing date, spacing and watering on the growth and yield of 4F cotton and on the interrelations of these factors have been confirmed by subsequent experiments in which other commonly cultivated varieties of American cotton were included. These experiments were carried out on light sandy soils deficient in nitrogen during the years 1940-42. The observational data included height, dry weight, boll counts, boll weights and yields. It would take much space to give the detailed results of these experiment and it is also considered unnecessary to do as they only confirm the above findings with some additional information. It would be enough, to economise space, to make a brief reference here to a $3^3 \times 2$ experiment conducted during 1941-42 in the same square of land as the 1939-40 experiment. The treatments comprised all combinations of:

Factors	*Sowing date*		*Variety*		*Nitrogen*
Levels	$d_1 = 15/5$, $d_2 = 31/5$, $d_3 = 20/6$	×	v_1 = 4F, v_2 = L. S. S., v_3 = 289F/43	×	o = control, ne = 50 lb. N before sowing, nl = 50 lb. N on 31/8

in 6 nine-plot blocks with subplot arrangement for two spacing types (close, normal). Inspite of the fact, the level of yields in this experiment was double that of the one already discussed, owing to the favourable soil and weather conditions, there was remarkable similarity in the trends of the treatment effects of the two experiments. The yield results are condensed in Table XVII.

TABLE XVII

Important interaction in 1941-42 experiment

Sowing date and nitrogen

	d_1	d_2	d_3
o	16·65	17·77	16·26
ne	22·78	23·16	20·80
nl	23·54	22·82	20·06
$ne—o$	6·13**	5·40**	4·54**
$nl—o$	6·89**	5·05**	3·79**
S. Ed ±0·803			

Spacing and nitrogen for d_3

	s_1	s_2	Diff. ±0·777
o	17·07	15·46	—1·61*
ne	21·99	19·61	—2·38**
nl	22·91	17·90	—4·31**
$ne—o$	4·92**	4·15**	...
$nl—o$	5·14**	2·44*	...
S. Ed ±1·145			

Variety and nitrogen

	v_1	v_2	v_3
o	16·81	19·38	14·49
ne	20·99	25·14	20·61
nl	22·09	24·94	19·38
$ne—o$	4·18**	5·76**	6·12**
$nl—o$	5·28**	5·56**	4·89**
S. Ed ±0·803			

Sowing date and spacing

Spacing	d_1	d_2	d_3
s_1	20·48	21·48	20·42
s_2	21·49	21·06	17·66
Diff. ±0·449	1·01*	—0·42	—2·76**

Differential responses to spacing ($s_2—s_1$)

Variety	d_1	d_2	d_3
4F	1·84*	—1·67*	—2·43**
L. S. S.	...	1·30	—1·61*
289F/43	1·20	—1·03	—4·25**
S. Ed ±0·777			

The decline in the response to nitrogen as sowings are delayed has been steeper with the August application as compared with the early manuring. There is an indication that early sowing should preferably be manured near flowering while the response in case if later sowings can be improved to some extent if application is made before sowing or if closer spacing is adopted. The results are again in favour of close spacing for the later sowings. The effectiveness of close spacing for late sowing is, however, particularly marked in case of the erect growing type 289F/43 or midiumly spreading variety 4F. The varieties do not appear to differ very widely in their response to nitrogen.

Summary

The investigation describes the results of factorial experiments with Punjab-American cottons on light sandy soil at the Lyallpur Agricultural Farm. The interrelations of four factors, viz. sowing date, nitrogen, water supply, and spacing have been studied, and the effectiveness of late sowings as an alternative ameliorative measure for *tirak* has been explored.

Delay in the sowing of cotton by a given period does not cause an equivalent delay in the reproductive phase. The commencement of flowering is shifted forth only by about 1/3 the interval between sowings. The peak and the cessation of flowering are still less affected. The plant exhibits photoperiodism. As flowering retards the vegetative activity of the plant, less and less period is at the disposal of the successive sowings for the production of dry matter which, therefore, falls in proportion to the delay in sowing. The meristematic activity, as given by the number of nodes and flowers, falls off progressively according as the dry weight is reduced in the later sowings.

There is a steady increase in the setting percentage as well as boll weight with delay in sowing. These counterbalancing tendencies raise the yield status of later sowings under unmanured conditions.

Nitrogen application as well as late sowing individually increase the N-concentration and correspondingly the boll weight. The two factors, therefore, are analogous in their effect.

The plant growth under the different sowings is differently affected when nitrogen is applied. The beneficial effects of nitrogen on the dry weight, the weight of seed cotton per boll and the yield diminish as sowing is deferred. Similarly increase in boll number with nitrogen application is not as high in the third sowing as in the first two sowings.

There is luxury consumption of nitrogen in the late-sown nitrogen treated plants. The high concentrations of nitrogen under these conditions get only incompletely depleted, as this surplus is neither utilized for boll development nor it takes part in growth.

Widely-spaced plants grow taller and produce greater dry matter in comparison to the individuals under close spacing. On area basis, the compensatory growth is incomplete in any of the three sowings. Boll number and yield under wide spacing are, however , made up in the first two sowings, but the compensation is inadequate in the last sowing. The last should therefore, be spaced close.

Close spacing is more efficient in the removal and the utilization of nitrogen as compared with the wide spacing (specially in the later sowing). This effect is well pronounced on vegetative and also the reproductive development.

Mean response to water is small and general. It has shown no interaction with any other factor.

Acknowledgement

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CYTOLOGICAL INVESTIGATIONS ON AUTO- AND ALLO-TETRAPLOID ASIATIC COTTONS

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(With 23 text-figures)

The earliest cytological report on the behaviour of autopolyploids in cotton is that of Skovsted [1933] wherein he has described the meiosis of a triploid Asiatic cotton, which originated from a cross between the F1 of *G. herbaceum* L (H3) and *G. arboreum* L var rubicunda (Watt) designated as N 8-2 and a multiple recessive strain extracted from a cross between two closely related *G. arboreum* varieties. According to him, probably a thirteen chromosome egg had either been doubly fertilized or more probably fertilized by an accidental diploid pollen grain. In 1940, two more papers appeared on the cytology of autopolyploids which were obtained by colchicine treatment. Nakatomi [1940] described the meiosis of an Asiatic autotetraploid cotton, but the original of his work was not available to the author of the present paper owing to the present international situation. The other paper is that of Mendes [1940], describing the meiosis of an octoploid *G. hirsutum* L. As the present paper was being prepared by the author, Beasley's [1942] and Stephens' [1942] papers on the meiosis of polyploids were available. The former has described the meiosis of an autotetraploids *G. herbaceum* L and the latter the meiosis of an autotetraploid *G. arboreum* Var *neglectum* Watt. The object of the present paper is to present a cytological account of the tetraploid cottons obtained by doubling the chromosome numbers of *G. herbaceum* L, *G. arboreum* L and of the F1 hybrids between the above two species. A short account of the meiosis of an F1 hybrid plant between an Asiatic autotetraploid and a cultivated American cotton with 52 chromosomes is also given.

Material and methods

At the Agricultural Research Station, Surat, a number of cultivated Asiatic cottons were treated with colchicine during the seasons 1939-40 and 1940-41 and were maintained as ratoons during the seasons 1941-42 and 1942-43. The method of treating the plants with colchicine and the morphological accounts of the tetraploids obtained have been described by Amin [1940; 1941]. The following tetraploids were investigated cytologically during the season 1941-42.

(1)	*G. herbaceum* L var frutescens-Delile	Strain Surat-1027 A. L. F.
(2)	Ditto .	Strain 1 A.-Long boll
(3)	*G. arboreum* L var typicum forma bengalensis . . .	(H & G)-Red arboreum
(4)	*G. arboreum* L var neglectum Watt, forma indica . .	(H & G) strain Gaorani 6
(5)	*G. herbaceum* × *G. arboreum* F1	(1027 × G. 6)
(6)	Ditto × Ditto F1	(1027 × Red arboreum)
(7)	Ditto × Ditto F1	(1 A. L. B. × Red arboreum)

Tetraploids 1 to 4 are considered as true autotetraploids since they are obtained by doubling the chromosomes of pure diploid species. They have four sets of identical genoms and are designated as 4 A1 or 4 A2 [Beasley 1940; 1942] where A1 and A2 indicate an *herbaceum* and an *arboreum* genom respectively. Tetraploids 5 to 7 are allo-tetraploids and their chromosome formula may be designated as 2 (A1 A2).

In the tetraploids under study no root tips were available for somatic counts. Tetraploidy of the plants was established solely by meiotic counts. Flower buds were collected between 10 A.M. and 12 noon and fixed either in acetic—alcohol (1 : 3) or Carnoy. These were stained with iron-acetocarmine and temporarily sealed for examination. Flower buds were also sectioned by the usual paraffin method and stained with gentian violet. For the examination of somatic chromosome numbers of the progeny of the polyploids under study, root tips were fixed in 'Craf' and stained with crystal violet. Drawings were made with the aid of a Camera lucida, at bench level, using a 1·8 achromatic objective and X15 and X20 compensating oculars.

Fertility of the tetraploids

The autotetraploids under study did not set any bolls either by selfing or by open pollination. They, however, cross with the cultivated American cottons. The allotetraploids were found to be partly fertile either by open pollination or by selfing. Stephens [1942], however, finds some fertility in his autotetraploids either by selfing or by open pollination.

Meiosis in the tetraploid Asiatic cottons

As the course of meiosis is in general, more or less alike in both the auto- and allo-tetraploids under study, description of meiosis will be confined to the *herbaceum* (1027 A. L. F.) tetraploid in detail.

The pollen mother cells of the tetraploid are, in general, bigger than those of the diploid. A detailed account of early prophase is not attempted in this paper as it was found extremely difficult to make out the details reliably. At pachytene, the threads are extremely long and it is very difficult to follow the

paired chromosomes completely as they take a very tortuous course in the nucleus. The nucleolus is prominent and shows vacuoles. The attachment of some of the threads to the nucleolus is clear at four points but it is difficult to say how many chromosomes are attached.

Figs. 1, 2*a* and 2*b* show nuclei in the late diplotene stages. In all these figures, the quadrivalent nature of some of the bodies could be made out. Trivalents and univalents are also noticed. At late diplotene, the nucleolus is still very large and vacuolated and some of the bodies are in contact with them. In Fig. 2*b*, three bodies are attached to the nucleolus of which one is a quadrivalent and two are bivalents. Fig. 4 shows a diakinesis nucleus in the diploid 1027 A. L. F. Of the four bivalents around the nucleolus, two are in contact with it and the other two are in a different focus. Abraham [1940, 1] also figures a diplotene in an *arboreum* strain where he shows three bodies around the nucleolus of which two are probably in contact with the nucleolus. Jacob [1941, 1, 2 ; 1942] using Feulgen-fast green technique, has shown, in somatic cells of Asiatic cottons, that there are two satellited chromosomes and two secondarily constricted chromosomes and at prophase of meiosis four chromosomes are attached to the nucleolus. These show that in the diploid four chromosomes and in the tetraploid eight chromosomes are attached to the nucleolus.

At diakinesis, the bodies get more condensed and become distinct (Fig. 3). Quadrivalents and trivalents could be made out at this stage clearly. The nucleolus gets considerably reduced and in some cases it is even lost. As such the relationship of the chromosomes to the nucleolus gets inconstant. The number of chromosomal bodies range from 14 to 25 (as examined from 15 nuclei) depending upon the number of multivalents, bivalents and univalents formed. Quadrivalents of various shapes are also seen in the figure.

FIG. 1

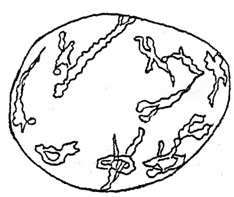

FIG. 2

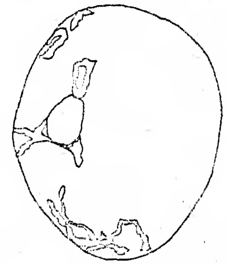

FIG. 2*b*

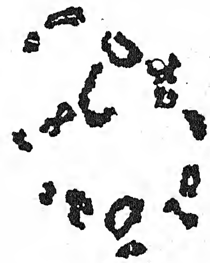

FIG. 3

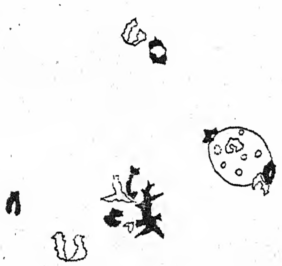

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

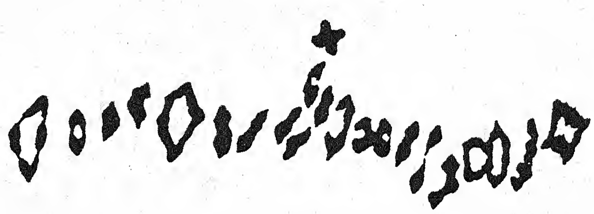

FIG. 9

FIG. 10

FIG. 11

FIG. 12

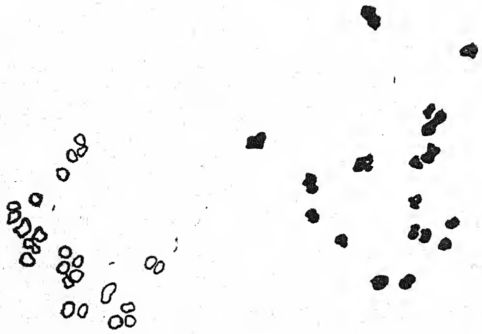

FIG. 13

FIG. 14

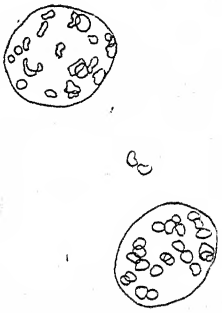

FIG. 15

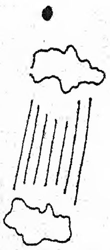

FIG. 16

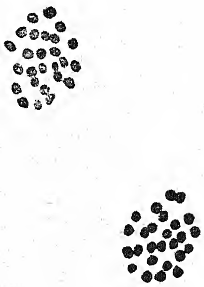

FIG. 17

FIG. 18

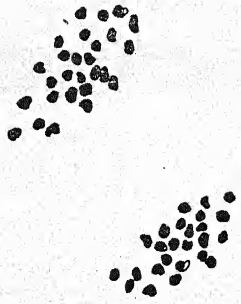

FIG. 19

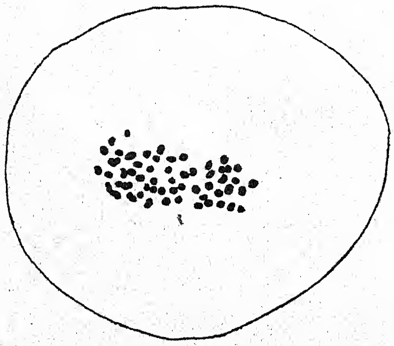

FIG. 20

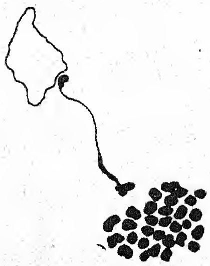

FIG. 21

FIG. 22

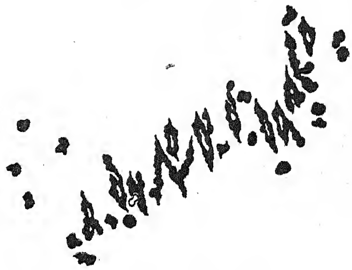

FIG. 23

EXPLANATION OF TEXT-FIGURES

N.B.—All figures excepting those that are specially mentioned belong to the tetraploid *G. herbaceum* (1027 A.L.F.)

FIG. 1.—Diplotene. Nuclear wall not shown. Acetocarmine smear × 792
FIGS. 2*a*, 2*b*.—Diplotene drawn at two foci. Gention violet preparation × 1375
FIG. 3.—Diakinesis. (Nuclear wall not shown) showing 11 IV and 4 II. Acetocarmine smear. × 1187
FIG. 4.—Diakinesis in diploid *G. herbaceum* (1027 A. L. F.) showing 13 bivalents and a large vacuolated nucleolus. (Nuclear wall not shown) Acetocarmine smear. × 917
FIGS. 5 to 11.—Gentian violet preparations showing metaphase I. × 2750
FIG. 5.—*G. herbaceum* (1027 A. L. F.) diploid showing 13 II
FIG. 6.—Tetraploid 1027 A. L. F. showing 13 quadrivalents.
FIG. 7.—*G. arboreum* (Red arboreum) tetraploid showing 2 II and 12 IV
FIG. 8.—Showing 10 IV and 6 II
FIG. 9.—Showing 6 IV and 14 II
FIG. 10.—Showing 7 IV and 12 II
FIG. 11.—Showing 8 IV+1 III+7 II+3 I Anaphase I has already started in this nucleus. Probably the two univalent chromosomes (judging from their position) must have formed a bivalent earlier and separated precociously. Note the large ring quadrivalent beginning the anaphase.
FIGS. 12 to 14.—Anaphase I. Acetocarmine smears. × 1187
FIGS. 15 to 18.—Gentian violet preparations. × 1375
FIG. 15.—Interkinesis showing a univalent dividing and left in the cytoplasm. (All chromosomes not shown in the daughter nuclei).
FIG. 16.—Telophase I, showing a univalent away from the spindle
FIG. 17.—Metaphase II showing 26/26 distribution
FIG. 18.— Ditto. showing 28/24 distribution
FIG. 19.— Ditto. showing 27/25 distribution. Acetocarmine smear × 1187
FIG. 20.—Fusion of second metaphase plates. Anaphase II has already started to form a dyad. All chromosomes not drawn. Gentian violet preparation. × 1375
FIG. 21.—A bridge at metaphase II in the tetraploid (1027 × G. 6) Acetocarmine smear. × 1187
FIG. 22.—Anaphase II. Acetocarmine smear. × 1187
FIG. 23.—Mataphase I. In the F1 hybrid between *G. herbaceum* tetraploid (1 A. L. B.) and *G. hirsutum*. (Co. 2). Acetocarmine smear. × 1187

At metaphase I, the chromosomes are much more condensed. Sometimes, the details of the quadrivalents, as has also been pointed out by Beasley [1942], are difficult to make out. The shapes of the quadrivalents seen are single rings of four, double rings, Vs, Ns, Ks, Xs, linear chains, etc. (Figs. 6 to 11). The first three are much more frequent than the others. The number of chiamsmata in the quadrivalents varied from 3 to 5. The mean number of chiasmata per quadrivalent was found to be 3·97 as judged from 43 quadrivalents. In the quadrivalents many of the chiasmata were found to be terminalized. Sometimes subterminal chiasmata were seen. All the five types of orientations, viz. parallel discordant, convergent, linear and indifferent were met with in the quadrivalents. In many cells the congression of the bivalents and multivalents was so good that it was found impossible to analyse such cells.

Often, the congression was disturbed. Figs. 6 to 11 show the various types of chromosome conjugation at metaphase I. Fig. 5 shows a polar view of the diploid 1027 A. L. F. at metaphase I, showing 13 bivalents. Fig. 6 shows 13 quadrivalents in the tetraploid 1027 A. L. F., drawn at the same magnification as Fig. 5.

An analysis of mataphase I showed the range of quadrivalents from 13 to 2. Of the 93 cells examined in this material, in 50 cells full conjugation of bivalents and quadrivalents is seen. In the rest, trivalents and univalents are also seen in addition to bivalents and quadrivalents. Beasley [1942] found in his analysis of 14 cells of *G. herbaceum* tetraploid, quadrivalents ranging from 7 to 12, with an average of 10 quadrivalents per cell. Since the maximum pairing of 13 quadrivalents is met with rarely, this type of conjugation is not seen in his data. The average number of quadrivalents in the material

under study is 8·06. Such slight differences in means may be possible, as chromosome conjugation is influenced by various other factors besides chromosome homology.

Stephens' [1942] analysis of the autotetraploid *G. arboreum* is somewhat different from those of the author of the present paper and of Beasley [1942]. The origin of the autotetraploid investigated by the former is, however, different from those of the latter two. Stephens [1942] gets a mean of 6·6 quadrivalents. The mean number of bivalents is only 4·3. The univalents and trivalents are of about the same level as the materials under investigation (Table I) Higher multivalents are frequently seen in Stephens' [1942] data. In the present analysis they are practically absent. It is possible that such variations in higher multivalent formations may be due to variations in autosyndesis, especially so in the plants whose chromosomes are very small. Such variations in autosyndetic pairing leading to higher multivalents are also met with in the allotriploid cottons of Asiatic and cultivated American origin. The range of association in Stephens' [1942] data is from 9 to 17; in the present analysis it is from 13 to 25.

TABLE I

Mean chromosome conjugation in auto- and allo-tetraploid Asiatic cottons at metaphase I

Chromosome configurations	Autotetraploids					Allotetraploids		
	G. herbaceum L		*G. arboreum* L			*G. herbaceum* L X *G. arboreum* L		
	1027 A. L. F.	1 A. L. B.	Gaorani 6	Red arboreum	N. 14 (Stephens data-1942)	1027× G. 6	1027× Red-arboreum	1 A. L. B., ×Red-arboreum
Univalents	0·95	0·65	0·55	0·97	0·7	1·03	0·98	1·45
Bivalents	9·04	8·89	8·25	8·35	4·3	10·50	12·59	11·55
Trivalents	0·24	0·17	0·29	2·38	0·3	0·30	0·53	0·28
Quadrivalents	8·06	8·26	8·49	8·29	6·6	7·27	6·08	6·66
Pentavalents	..	..	..	..	..	..	..	..
Hexavalents	..	..	0·02	..	0·9	..	..	..
Septavalents	..	..	..	..	..	..	..	..
Octovalents	..	..	..	..	1·0	..	..	..
Ninevalents	..	..	..	..	..	..	..	..
Decavalents	..	..	..	..	0·2	..	..	..
Total No. of p.m.c.	93	46	55	34	10	30	49	29
Mean number of association per p.m.c.	18·29 ±0·29	17·93 ±0·45	17·58 ±0·42	18·00 ±0·46	14·0 ±0·80	19·07 ±0·57	20·16 ±0·56	19·97 ±0·61
G. mean of associations per p.m.c.			17·9±0·20			19·8±0·13		

Differences within auto-and allo-tetraploids not significant. Differences between Auto- and Allo-tetraploids compared as two groups significant.

Table I also shows the mean chromosome conjugation and association in the other autotetraploids and the allotetraploids under investigation. In all the autotetraploids the mean number of quadrivalents is about the same (about 8). In the allotetraploids, though we get the same range of quadrivalents as in the autotetraploids, the mean number of quadrivalents is slightly reduced. Since in the diploid hybrid between *herbaceum* and *arboreum*, there is a reduction in the chiasma frequency at metaphase I, as compared with the pure species [Skovsted 1933; Webber 1939], it is possible to expect also a reduction in chiasma frequency in the allotetraploids and a consequent formation of less number of quadrivalents as compared with the autotetraploids.

Anaphase I and telophase I are mostly regular. The univalents either pass to one of the poles or sometimes divide and the divided halves pass to the two poles. Of the 62 nuclei examined only in four cases lagging chromosomes were noticed. Figs. 15 and 16 show such laggards at interkinesis and telophase I respectively. Such cases where anaphases are clean without any lagging univa-

lents are reported in other autotetraploids where a high number of quadrivalents are formed, as in tetraploids of *Primula sinensis* [Darlington, 1931], *Cicer* [Ramanujam and Joshi, 1941], *Carex siderosticta* [Tanaka, 1940], etc. The distribution of chromosomes at anaphase I is given in Table II.

TABLE II

Investigator	Chromosome distribution at anaphase I				
	26/26	25/27	24/28	23/29	Total
Beasley [1942] . . .	11	8	2	1	22
Present data . . .	10	8	1	1	20

It is seen, that equal distribution of chromosomes is much more frequent than other distributions. Similar results are obtained in many autotetraploids.

Fig. 14 shows an anaphase I, in the autotetraploid 1027 A. L. F., with 27 chromosomes in one pole and 25 at the other. In such cases the total number of bodies will be 52 or may sometimes be one more or less, depending upon the behaviour of the univalents. In some cases, however, the total number of bodies was much less than 52, suggesting that the four chromosomes of the quadrivalent have not all been separated by the repulsion force set up at anaphase and the chiasmata holding the chromosomes have not completely unravelled. In Fig. 12, there are 33 bodies on the whole, of which 14 are in one pole and 19 at the other. Some of the bodies have two chromosomes, some three, one suggest four, and some show only single bodies. A similar behaviour is also shown in Fig. 13. These suggest that in some of the quadrivalents the separation of chromosomes is in a 3/1 manner and in some the distribution is 2/2. In Fig. 12, where a body with four chromosomes is seen, it is possible that a quadrivalent has passed as such to a pole. Such cases of non-disjunction where multivalents have passed as such to the poles have been reported in the autotriploids of rice [Ramanujam, 1937], where the abnormality is still greater. In *Prunus* [Darlington and Moffett, 1930] and *Ribes* [Meürman, 1928], such abnormalities persist up to second division. In the tetraploids under study, the author has also noted at metaphase II, cases where there are 20 bodies in one plate and 22 at the other, suggesting that some of the bodies are composed of two or more chromosomes and are still held by chiasmata. Cases of non-disjunction where bivalents have passed as such to the poles have been recorded in cotton by Feng [1935] and Webber [1939].

While the formation of quadrivalents need not be a barrier for fertility in many plants, the nature of anaphase separation of the quadrivalents leading to the formation of gametes with unbalanced chromosome numbers, is taken as an explanation for the cause of sterility by some workers. Upcott [1935] considers that the low seed production, in the tetraploid *Solanum lycopersicum*, may be explained by the observed frequency of non-disjunction from quadrivalents. Müntzing [1936], Camera [1936], Randolph [1941] and others, however, consider that mere chromosomal irregularities are insufficient to account for the sterility in many autotetraploids but other factors should also be considered. Raptopoulos [1941] considers that certain descrepancies in the correlation between the number of quadrivalents and fertility may be due to differences in the relative co-orientations of their multivalents. Under such conditions, the author of the present paper feels, that in the polyploids under study, the differences in fertility may not be wholly due to the meiotic irregularities caused by multivalent formation. Further studies are necessary to explain fully the differences in sterility between the auto- and allo-polyploids under study.

Metaphase II is normally regular in having only two plates (Figs. 17 to 19). Of the 106 nuclei examined at this stage only in 21 nuclei (19·8 per cent) one or two lagging chromosomes were seen. Stephens [1942] gets about 12·5 per cent irregularity at this stage. The lagging chromosomes were found to form their own tiny pollen grains, as was actually seen at sporad and pollen grain stages. Sometimes a metaphase with three plates was seen. In one such case, there were 18 chromosomes in one plate, 21 in the second and 13 in the third. Such plates give a hexad sporad after the divisions are complete. Sometimes, fusion of two sister metaphase plates was noticed (Fig. 20). Such cases ultimately lead to a dyad sporad after the end of the division. Sporad analysis shows dyads. Somme [1930] reports such fused second metaphase plates in the autotetraploid *Primula sinensis* and Jørgensen [1928] in the autotetraploid *Solanum nigrum*. Though many cells at metaphase II are regular, the number of chromosomes in each plate is, however, variable as shown in Table III.

TABLE III

Investigator	Chromosome distribution at metaphase II					
	26/26	25/27	24/28	23/29	22/30	Total
Present data . .	30	24	19	3	1	77
Stephens' data (1942) .	17	10	6	2	0	35

As in anaphase I the mode is at 26/26. The composition of the 26 chromosomes depends upon

the type of distribution of chromosomes at anaphase I, i.e. whether 2/2 or 3/1. When quadrivalents are formed and if 3/1 distribution of chromosomes takes place at anaphase I, the conditions required to get 26/26 distributions of chromosomes are : (1) the number of quadrivalents in a nucleus must be in an even number, and (2) there must be equal chance of 3/1 separations. Though the two daughter cells have 26 chromosomes each, the number of each kind of chromosomes triplicated will be different in each daughter nucleus.

In the allotetraploid (1027 × Gaorani 6), a long bridge was seen at metaphase II, running from one plate to the other (Fig. 21). No fragment was seen. Bridges at metaphase II have been reported by the author [Iyengar, 1942, 2] in the triploid hybrids between Asiatic and American cottons. Recently, Beasley [1942] has drawn attention on the significance of bridges in cotton, from a speciation point of view.

Anaphase II is mostly regular. Of the 52 nuclei examined at telophase II, only 6 showed lagging chromosomes (11·54 per cent). Stephens [1942] obtains a more or less similar value. Fig. 22 shows a case where there are 25 chromosomes going to each pole in one spindle and 27 to each pole in the other spindle. In this pollen mother cell, 25 chromosomes must have gone to one pole and 27 to the other at anaphase I. The resulting sporads form four spores, of which, two will have 25 chromosomes and the remaining two will have 27.

Sporads are mostly regular and are composed of four spores of equal size. An analysis of 400 sporads showed 26 per cent irregularity. Most of the abnormal sporads had 1 to 8 supernumerary microspores. Dyads, pentads and hexads were rarely seen. Stephens [1942] finds in his material, 98 per cent of the ' tetrads ' normal ; the remaining 1·2 per cent were all triads and supernumerary microspores were not found.

Table IV shows the percentage of abnormal sporads and of bad pollen in some of the tetraploids under study.

Table IV

Tetraploids	Percentage of abnormal sporads	Percentage of bad pollen
1027 A. L. F.	26	92
1 A. Long Boll	8	99
Gaorani 6	16	84
1027 × Gaorani 6 F1	6	46
1 A. L. B. × Red arboreum F1.	4	79

It is seen, that though the percentage of abnormal sporads is relatively low, the percentage of bad pollen is very high in all the cases. The estimation of good and bad pollen was made from fresh flowers whose anthers were about to burst and examined between 10 and 11 A.M. The anthers were teased and the pollen was mounted in lactic acid. A cover slip was then gently applied. The good and bad pollen could be made out clearly. The high percentage of bad pollen shows, that degeneration is caused by factors other than mere cytological irregularities met with in the polyploids under study. A similar behaviour has been reported in autotetraploids of other genera where latter stages of meisis after mataphase I are fairly regular and result in normal sporads but the percentage of bad pollen is remarkably high.

Chromosome distribution in the progeny of allotetraploids

Somatic chromosome counts of 27 plants in the progeny of the allo-tetraploids (1027 × Gaorani 6) showed that two had 51, twenty had 52, four had 53, and one had 54 chromosomes. Similarly, in the cross [tetraploid (1027 × G. 6) × cultivated Americans], of the 32 F1 plants examined for somatic chromosome numbers, one had 51, twenty-six had 52, and one had 52+1 fragment, two had 53 and two had 54 chromosomes. The above observations indicate that in the tetraploids under study, gametes with 26 chromosomes seem to function most. Stephens [1942] found that all the F1 plants between autotetraploid *G. arboreum* × diploid wild cottons, had 39 chromosomes. Further we have reason to believe that the gametes with 26 chromosomes have two full sets of Asiatic chromosomes as shown by Stephens' [1942] analysis of chromosome conjugation in the triploid hybrids mentioned above and by the author's analysis of chromosome conjugation in an F1 hybrid between an autotetraploid Asiatic cotton and a cultivated American, as will be seen in the following section of the paper.

Meiosis in the F1 hybrid between the autotetraploid (*G. herbaceum* 1 A. long boll) and *G. hirsutum* (strain Co 2)

As previously stated, the autotetraploid Asiatic cottons are highly pollen sterile but the *herbaceum* autotetraploids cross with the cultivated American cottons. The resulting hybrids were found to be completely sterile. One hybrid between the autoteraploid *G. herbaceum* (1 A. L. B.) and *G. hirsutum* (strain Co 2), which had 52 chromosomes (as judged from meiosis) was examined for chromosome conjugation at metaphase I. The analysis is given in Table V.

Fig. 23 shows 18 univalents, 3 bivalents, 8 trivalents and 1 quadrivalent. In some exceptional cases (not mentioned in the analysis), less than 13 univalents were noticed. Such a behaviour is possible, if pairing takes place within the chromosomes of D set or one of D set pairs with the chromosomes of A set. Univalents less than 13

TABLE V

Chromosome configurations					Number of P. M. Cells
Univalents	Bivalents	Trivalents	Quadrivalents	Pentavalents	
13	9	7	...	...	4
13	7	7	1	...	1
13	6	6	1	1	1
13	8	6	...	1	1
13	6	9	...	...	1
14	8	6	1	...	1
14	7	8	...	...	1
14	1	12	...	...	1
15	4	8	...	1	1
15	8	7	...	...	1
16	4	8	1	...	1
16	9	6	...	...	1
18	3	8	1	...	1
Total . 226	107	119	5	3	16
Mean . 14·13	6·69	7·44	0·31	0·19	

are reported in the hybrids between the Asiatic and cultivated American cottons [Webber, 1939 ; Beasley, 1942]. According to Skovsted [1937], in the F1 hybrid between *G. arboreum* and *G. trilobum*, there is both auto- and allo-syndetic pairing. The chromosomes conjugation in one such abnormal cell, in the hybrid under study, was found to be 11 univalents, 3 bivalents, 6 trivalents 3 quadrivalents and 1 pentavalent.

At anaphase I, lagging chromosomes and bridges were noticed. Metaphase II also showed irregularities. The resulting sporads showed abnormalities. Dyads and triads were frequently noticed.

The constitution of the hybrid under study is similar to that of Beasley's [1942] hybrid between the autotetraploid *G. herbaceum* and *G. hirsutum*. His drawings of a first metaphase shows many trivalents. He concludes that the chromosome composition of this type of hybrid and of Skovsted's [1934] 52 chromosome plants are essentially the same, in having 2A1 (AD) 1.

Of the 52 chromosomes in the hybrid under study, 26 are derived from the cultivated American parent and hence one A set and one D set of chromosomes are fully represented in the hybrid, on the assumption that the constitution of the American cultivated is 2 (AD). The remaining 26 chromosomes derived from the Asiatic autotetraploid parent may have several types of constitution depending upon the number of quadrivalents and the type of segregation taking place in the quadrivalents of the particular pollen mother cell from which the gametes with 26 chromosomes is derived. If the quadrivalents regularly separates in a 2/2 manner to the poles at anaphase I then the 26 chromosomes contributed by the autotetraploid will have two A sets fully represented. The constitution of the 52 chromosome hybrid obtained in the above manner will be 2A (AD). During the meiosis of such a hybrid, the range of chromosome conjugation will be 13 III+13 I to 13 II+26 I. Since there is some affinity between and within the chromosomes of A and D sets in the diploid hybrid itself, occasional quadrivalents are also to be expected. On the other hand, if the number of quadrivalents in the autotetraploid are in an even number and at anaphase I if 3/1 and 2/2 segregations take place in equal chances to the two poles, the 26 chromosome gametes, thus derived from the autotetraploid will have some chromosomes represented three times and some represented once. This replication depends upon the number of quadrivalents formed and thus the types of chromosome configurations to be expected in the hybrids will vary according to circumstances. A study of a number of hybrids is underway to see how far the above expectations are fulfilled.

DISCUSSION

Chromosome conjugation in autotetraploids

In an autotetraploid there are four sets of homologous chromosomes and in an ideal case quadrivalents corresponding to the basic set are formed, as in the tetraploids of *Datura* (Belling, 1927], *Melandrium album* [Ono, 1939] and *Gasteria* [Sato, 1939]. But such a condition does not always hold good in many plants. In the autotetraploid *Lycopersicum esulentum* with 48 somatic chromosomes we have different results. According to Jørgensen [1928] only one or two quadrivalents are formed. Lindstrom and Koos [1931] obtained mostly 12 quadrivalents and rarely bivalents. Lesley and Lesley [1930] found that seven quadrivalents are often formed but twelve quadrivalents were rarely seen. Upcott [1935] gets a range of 1-8 quadrivalents. Similar diversity of results are obtained in other autotetraploids as in *Primula sinensis* [Sömme, 1930 ; Darlington, 1931], barley [Peto, 1936 ; Von Bergh, 1936], etc. According to Darlington [1931], these differences in quadrivalent formation between the above genera are due to differences in the frequency of chiasma formation in the species. Tanaka [1940] points o t that the origin of the parent diploids and the physiological influence of the cytoplasm on the formation of fiuadrivalents, should also be considered.

In some autotetraploids chromosome conjugation is further complicated by structural changes like interchange. Here, besides quadrivalents and bivalents, higher associations like penta-

hexa-, and septa-valents are also met with. Such tetraploid interchange heterozygotes have been reported by Tanaka [1940] in *Carex siderosticta*, by Müerman [1929] in *Aucuba japonica* and others. Thus, chromosome association shows wide variations in autotetraploids from genera to genera, species to species and even within the species. These indicate that besides chromosome homology, other internal and external factors should also be considered.

In the case of cotton, the chromosome morphology of the Asiatic cottons shows size differences within the somatic complement [Skovsted, 1933, 1934 ; Arutjunova, 1936 ; Abraham, 1940 ; Jacob, 1942 and as examined by the author of this paper]. These differences in the length of the chromosomes may pa tly be responsible for the reduction in the expected numbers of quadrivalents. Secondly, according to Skovsted [1933], the Asiatic cottons are themselves polyploids and though normally regular bivalents are formed in the diploids, under some conditions, as when it is in the triploid condition (1933, 1934) and in haploid condition [as in the haploid American cottons (1933), where a few trivalents are formed] there is autosyndesis within the Asiatic complement. Such a behaviour may be shown in autopolyploids under some conditions. Recently Jacob [1941, 1, 2, 3 ; 1942] has pointed out that structural changes have played a part in the evolution of the Asiatic diploid cottons. Such changes may also influence the chromosome conjugation in the autopolyploids arising from such changed diploids.

Auto- and Allo-polyploidy

Kihara and Ono [1926] classified polyploids into two groups, i.e. auto- and allo-. But the boundary between these two groups has become more and more vague, as continuous relation exists between the two groups, as shown by a number of people.

From a chromosome pairing point of view, it is generally held that autopolyploids are differentiated from the allopolyploids by the number of multivalents formed during meiosis. But there are autopolyploids which form mostly bivalents as in *Solanum nigrum*, [Jrgensen, 1928]. *Solanum gracile* [Kagawa, 1937], *Tulipa chrysantha* [Upcott, 1939], etc. Kasparyan [1934] shows amphidiploids where chromosome behaviour is the same as in autopolyploids, as well as cases where there are regular pairing as in diploids and various intermediate cases. According to him, the tendency for multivalent formation depends more on the number of chiasmata norma ly formed by the chromosomes of the initial species than on the degree of homology of the different sets in the polyploid. Vorobiev [1934] says that the truer nature of any plant, particularly whether true auto- or allopolyploid, can be decided only by combining a genetical study with the cytological study, especially in view of the growing doubt as to the validity of chromosome conjugation as a criterion of homology. Mnützing [1936] points out that even in pronounced allopolyploids there must be considerable degree of autopolyploidy as the different genoms have a great deal in common. Stebbins [1940] under certain limitations, defines an autopolyploid as a polyploid of which the corresponding diploid is a fertile species, while the allopolyploid is a polyploid containing the doubled genom of a more or less sterile hybrid.

In cotton, we have two types of allotetraploids ; one resulting from a cross between two closely related species as *herbaceum* and *arboreum* where bivalents are formed at meiosis in the diploid F1. On doubling the chromosome number of the hybrid the allopolyploid formed shows a fairly high degree of quadrivalent formation as mentioned in the body of the paper. This situation is similar to the case in *Crepis* hybrids [Poole, 1931]. The behaviour of the other type of allotetraploids in cotton which are obtained by doubling the chromosome number of the F1 hybrids between *G. arboreum* and *G. anomalum* [Iyengar, 1942] ; *G. anomalum* and *G. Davidsonii* [Iyengar, unpublished] ; *G. thurberi* and *G. arboreum* [Beasley, 1940, 2] is different. These show mostly bivalents. The diploid F1 hybrids of these polyploids show a high degree of sterility but the polyploids are relatively much more fertile.

Summary

Meiosis has been described in the autotetraploid *G. herbaceum* (1027 A. L. F.). Chromosome conjugation was studied at metaphase I, in the autotetraploids of two strains of *G. herbaceum*, of two strains of *G. arboreum* and in the allotetraploids obtained from three hybrids between the above two species. A high proportion of quadrivalents is seen in all the tetraploids. On an average, the proportion of quadrivalents is slightly lower in the allotetraploids. Maximum association, leading to 13 quadrivalents, is met with rarely. Meiosis, at later stages, is in general regular and finally normal sporads are mostly formed. But the pollen is largely defective, particularly so in the autotetraploids.

The autotetraploids are pollen sterile and do not cross with the cultivated Asiatic diploids, but some success was obtained when the autotetraploids were crossed on to the cultivated Americans. The allotetraploids are self fertile to a certain extent.

The progeny of the tetraploids had mostly 52 somatic chromosomes, indicating that in the tetraploids gametes with 26 chromosomes seem to function most.

Meiosis in a sterile hybrid plant (2n=52) obtained from the cross between the autotetraploid *G. herbaceum* (1 A. L. B.) and *G. hirsutum* (Co 2), showed that many of the chromosomes of the three A sets are associated as trivalents and the chromosomes of D set, left as univalents. The sterility in this hybrid may be partly due to the irregularity initiated by the formation of trivalents and univalents in large numbers, caused by the constitution AA (AD).

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STUDIES ON THE ROOT ROT OF COTTON IN SIND, I

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Root rot is one of the more common diseases affecting cotton in India and has been recorded to be serious in the Punjab, Gujerat and Sind. This disease occurs in Sind every year and is responsible for causing considerable damage to the cotton crop in the province. Generally, the percentage of infection varies between 5 and 10 per cent but observations taken at Government Auxiliary Farm, Shahdadkote, show that the intensity of infection can be as high as 60 per cent. Vasudeva [1935], who investigated the problem at Lyallpur, found that both *Rhizoctonia solani* Kühu and *Rhizoctonia bataticola* (Taub) Butl. can cause the disease in the Punjab, while Likhite and Kulkarni [1934] are of the opinion that in Gujerat it is due to the combined effect of *Rhizoctonia bataticola* (Taub) Butl. and a nematode. The above workers obtained certain types of *Fusaria* along with *Rhizoctonia bataticola* (Taub) Rutl. in the isolations from the affected roots of cotton. Since there appears to be variation in the organism and symptoms associated with this disease, investigations were undertaken to determine the nature and the cause of this disease in Sind.

Symptoms

The first visible symptom of the disease is complete wilting of the plant. The affected plant can be pulled out easily from the soil. Practically all the lateral roots are destroyed. On squeezing the roots, a yellow liquid oozes out. The cortical tissues of the root become fibrus and the central woody portion turned brown and in severe cases of attack it becomes black.

In certain respects, the root rot of cotton in Sind resembles the root rot in the Punjab, Gujerat and Texas. The common symptoms at all the places are that the affected plants die suddenly, the roots of the plants become yellow in colour and on squeezing the roots, a yellow liquid oozes out. Peltier [1926] reports that the leaves of the plants attacked by root rot in Texas become yellow before the actual wilting starts. This symptom has not been observed either in the Punjab, Gujerat or Sind.

In Texas, the root rot is caused by *Phymatotrichum omnivorum* (Shear) Duggar. It is generally serious at the time of square formation. In Gujerat the disease appears when the flowers have been formed while in the Punjab it appears when the plants are about two months old. But in Sind the disease manifests itself when the plants are only 15 days old and continues up to the boll formation stage. Thus the disease in Sind appears much earlier and remains active for a longer period than in the Punjab or Gujerat.

Isolation

Two methods of isolation were used :

(*i*) By surface sterilization of the affected

portion in 0·1 per cent mercuric chloride solution and transferring these pieces aseptically to agar slants after washing them thoroughly in sterilized water.

(*ii*) Davies [1935] silver nitrate, sodium chloride method was used.

From almost all the pieces of infected tissue, *Fusarium*, *Rhizoctonia* and few other saprophytic fungi grew out in the course of a week. Over 700 isolations were made from different places. Saprophytic fungi like *Aspergillus*, *Pennicillium*, etc. were eliminated. The rest of the isolates were grouped under seven groups. For grouping these aerial mycelium, discoloration of the medium and spore-bearing structures were taken into consideration. Afterwards these groups were microscopically examined and slight differences were found to exist between them. The characters on which these groups were based are given in Table I.

TABLE I

Types of fungi isolated from cotton

Type No.	Aerial mycelium	Discoloration of the mycelium	Spore bearing structures
1	Whitish, fluffy	Light brown	None
2	Pinkish	Pink	None
3	None	None	Sclerotia abundant
4	Scanty, whitish	Dark brown	Sclerotia abundant
5	White	Dark brown	Sclerotia not abundant
6	Dirty white	Black	Sclerotia abundant
7	Buff	Brown	None

TABLE II

Number of isolates of each type obtained

Type No.	No. of cultures of isolates on 30-1-1939 Sakrand	30-4-39 Sakrand	15-9-39 Sakrand	30-5-39 Dadu	15-6-39 Mirpurkhas	1-7-39 Sakrand	1-8-39 Sakrand	3-9-39 Shahdadkot	Total No. isolates
1	5	11	7	6	11	7	3	22	67
2	2	3	6	0	2	8	2	7	28
3	9	7	5	0	9	9	5	25	60
4	3	2	2	5	1	11	0	6	30
5	11	5	10	7	0	13	9	10	54
6	6	8	0	0	3	2	0	11	24
7	7	0	0	0	0	3	3	13	28

In Table II are given the numbers of various types of isolates that were obtained at each isolation along with the locality from where the affected material was collected.

PATHOGENICITY TESTS

Inoculum of types 1-7 was prepared by growing these fungi in Erlenmeyer flasks on sterilized mixture of 190 gm. of soil and 10 gm. of wheat flour. To every 200 gm. of mixture 60 c.c. of water was added. Five flasks of each type were prepared. In about three weeks' time the cultures were ready to be transferred to the pots. 12 inch pots were two-thirds filled with sterilized soil. Half the contents of each flask were sprinkled over the sterilized soil. Six cotton seeds were placed on the inoculum in the pots. These seeds were covered with the other half of the inoculum which in turn was covered with sterilized soil. There were four pots of each type. In the pots kept as control, the seeds were sown between two layers of sterilized soil and wheat flour.

The seedlings emerged through the soil six days after the sowing. There was good germination in nearly all the pots. Twenty days after the sowing wilting appeared in pots inoculated with type 3. The wilting was very sudden and the plant was found in a drooping condition. In about a week's time in that series of pots practically all the plants died. Two days after the first wilting appeared, plants began to die in pots inoculated with types 1 and 5. The experiment was finished on 24 April 1939. Results obtained from this experiment are given in Table III.

The wilted plants were taken out and isolations made from them. In all the cases, the fungi obtained were the same as those they had been infected with. Some plants were found to be wilting in the control pots as well, isolations from such plants yielding fungi like *Aspergillus*.

It is clear from the above experiment that a type of *Fusarium* and two types of *Rhizoctonia* are capable of causing a disease in cotton similar to root rot in nature. By comparing the results of this experiment to the table of isolations, it is revealed that the isolates which were parasitic appeared most frequently at the time of isolations.

Infection experiment I

TABLE III

Germination and rotting with isolate Nos. 1 and 7

Types of isolates	No. of seedlings germinated	No. of seedlings rotted	Germination percentage	Rotting percentage
1	21	5	87·5	24·0
2	20	0	83·3	..
3	22	7	91·7	31·8
4	19	0	79·2	..
5	18	3	75·0	16·7
6	17	0	70·8	..
7	21	0	87·5	..
Control	23	0	95·8	..

The symptoms produced by *Fusarium* and *Rhizoctonia* resembled each other in all essential characteristics. The main difference between the two was that the discoloration produced by *Rhizoctonia* was very much darker than was the case with *Fusarium*.

EXPERIMENT II

Only isolates 1 and 3 were selected for further trial as these caused the greatest amount of damage. The inoculum was made in the usual manner. The following five series of pot culture were arranged.

(*i*) Pots having inoculum type 1 only, i.e. *Fusarium* alone.

(*ii*) Pots having $\frac{3}{4}$ inoculum from type 1 and $\frac{1}{4}$ from type 3, i.e. *Rhizoctonia*.

(*iii*) Pots having $\frac{1}{2}$ inoculum from type 1 and $\frac{1}{2}$ from type 3.

(*iv*) Pots having $\frac{1}{4}$ inoculum from type 1 and $\frac{3}{4}$ from type 3.

(*v*) Pots having inoculum from type 3, i.e. *Rhizoctonia* alone.

In the central pots the seeds were sown in between the layers of sterilized soil and wheat flour. Six seeds of cotton were sown in each pot.

The seedlings emerged through the soil six days after the sowing. The germination was good in all cases. In the pots having half and half inoculum from each type, the wilting appeared 19 days after sowing, while in other cases wilting appeared after 28 days. The results obtained in this experiment are given in Table IV.

Infection experiment II

TABLE IV

Germination and rotting with isolates 1 and 3

S. No.	Types of isolates	No. of seedlings germinated	No. of seedlings rotted	No. of days to rot	Germination percentage	Rotting percentage
1	*Fusarium* alone isolate No. 1 . .	21	14	26	87·5	19·0
2	$\frac{1}{4}$ *Fusarium*, $\frac{3}{4}$ *Rhizoctonia* . .	22	6	25	91·7	27·3
3	$\frac{1}{2}$ *Fusarium*, $\frac{1}{2}$ *Rhizoctonia* . .	20	16	19	83·3	80·0
4	$\frac{3}{4}$ *Fusarium*, $\frac{1}{4}$ *Rhizoctonia* . .	19	5	27	95·8	26·3
5	*Rhizoctonia* alone	23	6	25	95·8	26·0
6	Control without any inoculation .	24	0	..	100·0	..

It is quite clear from the above experiment that *Fusarium* (Type 1) and *Rhizoctonia* (Type 3) are more parasitic when together than either of them singly. When together they cause the disease to appear much earlier and the number of plants attacked is also much more.

The symptoms produced by *Rhizoctonia* and *Fusarium* in combination very much resemble that produced by *Rhizoctonia*. The discoloration of the roots is much more intense and the colour varies from dark brown to black. The discoloration is the deepest at the collar.

Morphology of the root-rot fungi

Isolates 1, 3 and 5 which caused rotting were selected for morphological study. Isolate No. I was a *Fusarium* while the other two belonged to the genus *Rhizoctonia*.

Both the isolates 3 and 5 were grown on oatmeal agar and potato dextrose agar along with a pure culture of *Rhizoctonia bataticola* (Taub) Butl. obtained from the Imperial Mycologist, Imperial Agricultural Research Insittute, New Delhi. They resembled each other in all essential characters. The diameter of the mycelium and of sclerotia was found to be the same in all cases. The isolate No. 5 differed from No. 3 only in the presence of a white fluffy mycelium.

Efforts were made to obtain the pycnidial stage. The fungi were grown on different media at different hydrogen-ion concentrations and at different temperatures. At no stage, pycnidia were found to appear. So the fungus has tentatively been given the name *Rhizoctonia bataticola* (Taub) Butl.

The isolate No. 1 was grown at a temperature of about 25°C. in tubes of media prepared according to the methods of Wollenweber *et al.* [1925] and its characters were noted on these media. The culture of this *Fusarium* was sent to the Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi, for identification. It has been identified by him to be *Fusarium coeruleum* (Lib) Sacc. The characters of this are as follows.

Spores are in cream coloured and bluish green sporodochia, typical martiella shape with distinct septations and rounded base and oblique tip. Mostly 3-septate chlamydospores are present terminal and inter-calary. Microconidia abundant in aerial mycelium in false heads. 3-septate macro-conidia measure $5\cdot0 \times 27\cdot6$ ($4\cdot6$—$6\cdot0 \times 24\cdot1$—$32\cdot5$) μ, giving a length to breadth ratio of $5\cdot5 : 1$.

Discussion

The isolations carried out from the rot affected roots of cotton have always produced *Fusarium coeruleum* (Lib) Sacc. and *Rhizoctonia bataticola* (Taub) Butl. and both of them have been found to be parasitic. *Rhizoctonia solani* Kühn which causes root rot of cotton in the Punjab has been found to be entirely absent. It has not even been obtained in one out of the 700 isolations. Nematodes, which are associated with the root rot of cotton in Gujerat, have also been found absent in Sind.

This study has confirmed the findings of Likhite and Kulkarni [1934] and Vasudeva [1935] that *Rhizoctonia bataticola* (Taub) Butl. is the chief cause of root rot of cotton in India. It has further shown that *Fusarium coeruleum* (Lib) Sacc. is also one of the important causes of root rot in Sind.

In the United States of America Woodroof [1927] has reported that a damping off disease in cotton is caused by *Fusarium moniliforme* Sheld. In Sind the root rot of cotton is also known to occur in early part of June when cotton is just in the seedling stage. Perhaps this might be comparable to the damping off of cotton seedlings in U. S. A. It is difficult to say at the present stage of knowledge that *Fusarium coeruleum* (Lib) Sacc. causes this disease in Sind while *Rhizoctonia bataticola* (Taub) Butl. is responsible for root rot of cotton at a later stage. Fact at present remains that both the fungi have been isolated at all stages of growth of cotton and both have been found to produce a similar disease in artificially infected pots. Further study of this problem will be able to throw a proper light on this important issue.

Summary

Isolations were carried out from rot-affected roots of cotton collected from different places in Sind. These gave cultures of *Fusarium* and *Rhizoctonia*. Both of these were found to be parasitic. They were found to be doing much more damage when both of them were together. They were identified to be as *Fusarium coeruleum* (Lib) Sacc. and *Rhizoctonia bataticola* (Taub) Butl.

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FURTHER STUDIES ON THE STEM-ROT DISEASE OF RICE CAUSED BY *SCLEROTIUM ORYZAE* CATT. IN THE PUNJAB

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Rice is one of the staple food grain crops of the Punjab hills. It occupies about one million acres. It is subject to a number of fungal diseases of which the Stem-rot is most serious and causes heavy damage. The loss due to this disease varies from year to year and place to place. In certain years, when the conditions are favourable for the disease, half to three-fourths of the crop is destroyed. The loss of 5 to 15 per cent of the crop is common every year. It amounts to several lakhs of rupees.

The disease occurs mostly in the Sheikhupura, Gujranwala, Karnal and Gurdaspur districts and is met with to a small extent in hills.

Some preliminary studies on this disease in the Punjab were conducted by Luthra and Sattar [1936]. They described the pathogenicity of the causal fungus (*Sclerotium oryzae* Catt.), symptoms, distribution and modes of perpetuation of the disease.

The present paper deals with the study of certain environmental factors affecting the incidence of the disease and its control measures.

Experimental

A. Material and methods

Rice seed for the experimental crop was obtained from he. Assistant Cerealist, Rice Farm, Kala Shah Kaku, and was grown by two methods, viz. (i) broadcast and (ii) transplanting of seedlings.

Before use the seed was disinfected in 0·1 per cent solution of mercuric chloride for 15 min. The soil was infected by adding to the upper 3-4 in. of it diseased rice stubble or pure culture of the fungus. The fungus was grown on husked rice and oatmeal agar (oatmeal 50 gm., agar agar 20 gm., made up to one litre in distilled water) at 25°C. and three weeks old culture thus prepared was used.

Manures were added two weeks after transplanting of seedlings. Each fertilizer was mixed with an equal amount of powdered soil before adding to the plots. This was done to facilitate application.

The experimental plots for control measures were separated from each other by 3 ft. high walls of unburnt bricks to prevent the transfer of diseased material from one plot to the other. Experiments were carried out at the Botanical Farm, Lyallpur, and the Rice Farm, Kala Shah Kaku.

B. Effect of sowing and transplanting rice on different dates

The sowing and transplanting of rice in the Punjab are started in the first week of May and continue to the middle of July depending upon the variety of rice to be grown, water supply, and local cultural practice.

In order to study the effect of sowing and transplanting of rice on different dates, in 1935 an uninfested piece of land was divided into small plots each measuring 25 × 3 ft. Rice No. Jhona 349 was used in the experiment. Sowing and transplanting were carried out after every fortnight. Sowing was started from 10 May and transplanting from 10 June and were continued to 25 August. For every planting forty-day-old seedlings were used. In each case soil was infected with the culture of the fungus five days before sowing and transplanting.

There were two sets of experiments. In set A, plants were thinned one month after sowing or transplanting and the other set B was not thinned. Other treatments in both cases were similar. The results are given in Tables I and II.

It will be seen from the results given in Tables I and II that sowings done on 10 July or later were practically free from the disease. But late sowings are not recommended as yield is reduced. In a locality where the disease is very serious late sowings would be useful.

(C) Effect of stagnant water

Water is a limiting factor in the success of rice. It is mostly grown in the semi-waterlogged areas. All cultural operations are done

TABLE I

Effect of different dates of sowing

Serial No.	Date of sowing in 1935	Percentage of diseased plants	
		Set A (Plants thinned)	Set B (Plants not thinned)
1	10 May	14·8	15·5
2	25 May	84·1	64·4
3	10 June	42·4	28·0
4	25 June	40·8	18·7
5	10 July	0·0	5·0
6	25 July	0·0	0·0
7	10 August	0·0	0·0
8	25 August	0·0	0·0

TABLE II

Effect of different dates of transplanting

Serial No.	Date of transplanting in 1935	Percentage of diseased plants	
		Set A (Plants thinned)	Set B (Plants not thinned)
1	10 June	43·4	38·4
2	25 June	31·5	33·3
3	10 July	0·0	0·0
4	25 July	0·0	0·0
5	10 August	0·0	0·0
6	25 August	0·0	0·0

in puddled conditions and water is kept stagnant throughout the growing period of the crop.

Ramiah [1937] pointed out that though in India it is considered essential to keep water always in the field throughout the growth of the crop yet in some countries, i.e. Italy, Spain and America, water is drawn off completely from the field now and then. It seems that rice can stand this treatment without any harm.

It was observed that the usual practice of keeping water stagnant in rice fields throughout the growing period, favoured the attack of the stem-rot disease. In order to confirm the observations, field and pot experiments were arranged.

Pots used for this purpose were cemented at the bottom and water was kept standing and maintained by periodical additions. For the study of effect of absence of stagnation in pots, water was applied in small quantities as required to maintain the plants and keep the soil moist. Similarly in the field plots, water was always kept stagnating. On the other hand, from the control plots water was drained off now and then by opening the bunds. For pot experiments No. Jhona 349 was used but in the field 19 varieties of rice were grown. In each pot five seedlings were transplanted. Soil of pots and field was inoculated with the culture of the fungus. Results of pot experiments are given in Table III and the field observations in Table IV.

TABLE III

Effect of stagnant water (pot experiments) in 1935

Pot No.	Percentage of diseased plants	
	Water stagnant	Control (water not stagnant)
I	100·0	0·0
II	100·0	0·0
III	100·0	0·0
IV	33·0	0·0
V	40·0	0·0
VI	25·0	0·0
VII	40·0	0·0
VIII	40·0	0·0
IX	20·0	0·0

TABLE IV

Effect of stagnant water in 1935

Serial No.	Variety	Percentage of diseased plants	
		Stagnant water	Control (water not stagnant)
1	Jhona 349	38·8	0
2	Mushkan 7	0·0	0
3	Sonkesar 225	81·5	4·7
4	Sathra 278	42·3	0
5	Sonpattar 14	50·0	0
6	Mushkan 41	0·0	0
7	38 A	25·0	7·7
8	14 (S)	58·3	0
9	337 (A)	11·1	0
10	Palman 46	23·5	0
11	32	0·0	0
12	K. V. 32	30·0	0
13	Basmati 3	4·2	0
14	128	41·2	25·0
15	Bara 62	13·3	0
16	Basmati 370	0·0	0
17	Dhan 21	57·1	10·0
18	Munji 22	54·7	6·2
19	Ranjha 360	50·0	0

It will be seen from Tables III and IV that the results of both the pot and field experi-

ments establish that stagnant water increases infection to a considerable extent. Periodical drainage of stagnant water results in the total elimination of infection or it appears only in mild form. Reyes [1929] stated that one of the predisposing causes of the disease is the presence of abundance of stagnant water.

Tullis and Cralley [1933] mentioned that of the various control measures the most promising appears to be withholding of stagnant water from the rice fields for some time prior to maturity, though enough should be present to keep the soil muddy throughout the growing season.

(D) Effect of manures

It has been commonly observed that potassic and phosphatic fertilizers tend to reduce the incidence of infection by certain fungi and on the other hand nitrogenous manures have been seen to promote infection. It was, therefore, deemed desirable to study the effect of different manures on the incidence of the stem-rot disease.

Manurial experiments were arranged at the Botanical Farm, Lyallpur in 1935, 1936, 1938 and 1939. For these experiments land was divided into sub-plots each measuring 25 × 6 ft. Between each series of two plots a buffer strip 3 ft. wide unsown was kept. Experimental plots were artificially infected with the culture of the causal fungus.

Six week old seedlings of type Jhona No. 349 were transplanted in 1935 and 1936, while Sonkesar 225 was used in 1938 and 1939.

The following manures were added two weeks after transplanting and control plots were kept.

1. Farmyard manure at the rate of 1000 md. per acre.
2. Sulphate of ammonia at the rate of 5 md. per acre.
3. Superphosphate at the rate of 2½ md. per acre.
4. Potassium chloride at the rate of 2 md. per acre.

The results are given in Table V.

Table V

The Effect of different manures

Serial No.	Treatment	Percentage of diseased plants				Average of all years
		1935	1936	1938	1939	
1	Sulphate of ammonia	13·7	21·9	39·1	36·6	27·8
2	Farmyard manure	4·9	11·4	8·0	18·0	10·5
3	Superphosphate	4·5	8·6	0·0	10·0	5·77
4	Potassium chloride	3·0	7·0	0·7	7·4	4·52
5	No manure (control)	2·9	4·3	1·5	8·3	4·25

From the results given above it will be seen that nitrogenous manures definitely increase infection. In the case of potassic and phosphatic fertilizers the disease was markedly less but it was greater than the control.

Cralley [1939] studied the effect of fertilizers on the stem-rot disease. He stated that nitrogenous and phosphatic fertilizers increased the severity of the disease. He further mentioned that application of potassium on the other hand did not increase the severity of the disease. He recommended the addition of sufficient potassium on the stem-rot infested fields. The authors are of opinion that under the Punjab conditions the addition of potassium will not prove useful. The only point of economic importance is to avoid the heavy application of nitrogenous manures in the diseased rice area.

(E) The relative resistance of various varieties of rice

Experiments on the relative resistance of various varieties of Punjab rice to the stem-rot disease were carried out at the Botanical Farm, Lyallpur, and the Government Rice Farm, Kala Shah Kaku. Nineteen varieties of rice were used in the experiment. The experiment was arranged in a naturally infested field at the Rice Farm Kala Shah Kaku, while at Lyallpur it was artificially infected with the culture of the fungus and diseased rice stubble. The results are given in Tables VI and VII.

From the results given in Tables VI and VII. it will be seen that some fine varieties of of Punjab, i.e. Nos. Basmati 370, Bara 62, Mushkan 7, Basmati 3 and Mushkan 41 are highly resistant, while Sathra 278, Sonkesar 225, Sonpattar 14 are most susceptible. The remaining varieties may be called tolerant to the disease.

(F) Control measures

For the direct control of the stem-rot disease of rice some experiments were conducted at the Botanical Farm, Lyallpur, and the Rice Farm, Kala Shah Kaku.

For these experiments a piece of naturally infested land was selected and divided into various sub-plots, each measuring 64 × 10 ft. at the Rice Farm Kala Shah Kaku and 15 × 15 ft. at the Botanical Farm, Lyallpur. Seedlings of variety No. Sonkesar 225 grown in uninfested soil were transplanted in the middle of July every year. The following treatments were carried out and control plots were kept.

1. Burning of rice stubble *in situ*.

TABLE VI

The relative resistance of varieties of rice to the stem-rot disease at Lyalpur

Serial No.	Name of variety	Percentage of diseased plants 1935	1936	1938	1939	Average percentage of diseased plants
1	Basmati 370 .	0	0	0·5	0·0	0·1
2	32 . . .	0	0	0	2·5	0·6
3	Mushkan 41 .	0	0	0·	7·3	1·8
4	Malster 346 .	..	..	0	3·6	1·8
5	Mushkan 7 .	0·0	4·5	0	0	1·1
6	Basmati 3 .	2·1	0	4·6	0·5	1·8
7	Bara 62 . .	6·7	0	0	0	1·7
8	Begmi 337A .	5·5	0	0	4·0	2·3
9	Dhan 202 . .	..	..	0	11·3	5·6
10	Dhan K. V. 22 .	15·0	0	9·5	0	6·1
11	Dhan 21 . .	9·7	0	0·7	2·8	3·3
12	Palman 46 .	11·7	4·0	4·1	5·3	6·2
13	Ranjha 360 .	25·0	4·0	0	3·5	8·1
14	Sathra 278 .	26·1	5·0	0	25·9	14·2
15	Jhona 349 .	19·4	25·5	0	1·5	19·1
16	128 . . .	33·1	28·0	18·9	3·7	20·9
17	38A . . .	16·3	64·0	1·3	3·6	21·3
18	Sonpattar 14 .	29·2	73·0	22·9	6·7	32·4
19	Sonkesar 225 .	43·1	42·8	24·8	23·0	33·3

TABLE VII

The relative resistance of varieties of rice to the stem-rot disease of rice at Kala Shah Kaku

Serial No.	Name of variety	Percentage of diseased plants 1935	1936	Average percentage diseased plants
1	Bara 62 .	1·9	0	0·9
2	Mushkan 7	2·3	0	1·1
3	246 . .	0	2·1	1·0
4	Basmati 370	3·3	0	1·6
5	K. V. 6 .	0	4·2	2·1
6	Jhona 349 .	3·3	1·4	2·3
7	Mushkan 41	1·0	5·0	3·0
8	Ranjha 360	6·1	0	3·0
9	K. V. 22 .	8·0	0	4·0
10	Malster 346	..	8·3	8·3
11	257 . .	..	14·2	14·2
12	378 . .	20·2	0	10·0
13	Begmi 337A	29·0	0·5	14·7
14	K. V. 38 .	28·4	0·9	14·5
15	Sonpattar14	61·8	2·5	32·1
16	Sonkesar 225	..	65·2	65·2
17	Sathra 278 .	100·0	45·6	72·8

2. Removal of stubble by beans of *Khurpa* (a country made hand tool).

3. Ploughing the rice field, collecting and destroying the stubble thus uprooted.

4. No treatment (control).

The above treatments were carried out after harvesting the crop. The results are given in Table VIII.

TABLE VIII

Results of experiments on the control of the stem-rot disease of rice at Lyallpur and Kala Shah Kaku Farms

Serial No.	Treatment	Percentage of diseased plants at Lyallpur Farm 1935-36	1936	Percentage of diseased plants at Kalashahkaku Farm 1935	1936	Average percentage of diseased plants
1	Burning of stubble *in situ*	21·0	14·3	46·8	11·4	23·4
2	Removal of stubble by means of *Khurpa* .	3·7	17·7	61·8	17·8	25·25
3	Ploughing and collection of uprooted stubble .	12·1	27·1	..	..	19·6
4	No treatment (control) .	34·7	30·5	67·2	20·0	38·1

From the results given in Table VIII, it is clear that the burning of stubble *in situ* is fairly effective. This method is cheap and easy to be carried out after harvesting the crop. Hence for simply controlling the disease by the sanitary measures, it is necessary that all the farmers in a locality should work in co-operation and carefully destroy the diseased stubble, which is the main source of carrying infection from crop to crop.

It was observed that the diseased stubble and the sclerotia of the causal fungus after the treatments had been done, were spread by strong winds and rainfall from the untreated to the treated plots. Young [1926] pointed out that infection is spread by soil, stubble and straw. Lester [1928] described that scalerotia are believed to be distributed by the irrigation water.

In order to prevent the importation of infection into fields, on which the effect of burning stubble for control of the disease was studied, the following precautions were adopted. In 1939 a naturally infested plot which had carried 37.8 per cent diseased plants in 1938 was divided into four sub-plots, each measuring 25 × 20 ft. A cross wall three feet high of *kacha* bricks was erected in between the experimental plots. Each plot received irriga-

tion by a separate channel and during irrigation every possible care was exercised not to allow water to pass from one plot to the other.

In two opposite plots burning of stubble *in situ* was done after harvesting the crop in 1938. The other two plots were left untreated. Seedlings of variety No. Sonkesar 225 (which is most susceptible to the disease) were grown in uninfested soil and transplanted on 25 July, 1939. The results are given in Table IX.

TABLE IX

Results of experiment on the control of Sclerotium oryzae *at the Lyallpur Farm in 1939*

Serial No.	Treatment	Total No. of plants	No. of diseased plants	Percentage of diseased plants
1	Burning of stubble *in situ*.	404	0	0
2	Untreated (control) . .	466	87	18·7
3	Burning of stubble *in situ*.	461	0	0
4	Untreated (control) . .	402	27	6·7

From the results given in Table IX, it will be seen that the burning of strubble *in situ* is a very effective operation for controlling the disease. It is suggested, therefore, to isolate the infected area by high and strong bunds, which will serve as effective barriers against the spread of secondary infection by wind and irrigation water.

SUMMARY

1. The importance and distribution of the disease caused by the fungus *Sclerotium oryzae* Catt. has been described. The disease is common in many rice growing districts of the Punjab and causes considerable loss.

2. The effect of certain environmental factors on the incidence of the disease has been studied. The important results are:

(a) Infection is reduced if late sowing and late transplanting are done but these are not recommended.

(b) Keeping water stagnant throughout the growing period of the crop increases the incidence of the disease. If water is drained off now and then the disease is controlled to a great extent.

(c) Application of nitrogenous manures favours the attack of the disease.

3. The relative resistance of 19 varieties of the Punjab rice has been tested. The results show that Basmati and Mushkan groups of rice are most resistant to the disease.

These varieties are:—

Basmati 370,

Basmati 3,

Mushkan 7,

Mushkan 41; and

Bara 62.

On the other hand Sathra and Son groups of rice are most susceptible to the disease and these varieties are:

Sonkesar 225,
Sonpattar 14; and
Sathra 278.

Other varieties tested are intermediate in this respect.

4. Various control measures were tried and the following are recommended.

(a) Diseased rice stubble should be burnt *in situ*.

(b) Strong and high bunds should be made round the infested fields. This will check the spread of the disease by wind and irrigation water.

(c) Water should not be kept stagnant throughout the growing period of the rice crop. Soil should be exposed to open air now and then.

(d) Disease resistant varieties of rice should be grown.

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SOME RARE AND NEW SMUTS FROM INDIA

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(Received for publication on 3 March 1943)

(With two text-figures)

A majority of the smuts on which this report is based were collected in different parts of India and sent to me for determination. Among those who sent specimens are Dr L. Bor, Mr A. N. Fotidar, Dr P. Maheshwari, Dr B. P. Pal, Dr Pushkarnath and Mr M. J. Thirumalachar. Portions of specimens were also given by Mr K. M. Thomas from the Coimbatore Herbarium.

I take this opportunity of expressing to all of them my gratitude for the favour they have done by donating the specimens. I am also grateful to Rev. Fr H. Santapau, S. J., Professor of Botany, St Xavier's College, Bombay, for the latin translations of the diagnosis of the new species. The specimens are deposited in the *Herb. Crypt. Ind. Orient.*

USTILAGINACEAE

1. Ustilago andropogonis-finitim Maublanc, Bull. Soc. Mycol. Fr. 22 : 74, 1906

In the ovaries of *Cymbopogon flexuosus* Wats. Nandi Hill (Mysore), 21 March 1942, leg. M. J. Thirumalachar. Maublanc was apparently not certain whether his fungus is a *Cerebella* or an *Ustilago*, for the caption under the figure illustrating this smut reads " *Cerebella* (*Ustilago*) *Andropogonis-finitimi*". Germination of the spores, which I have observed and which is by means of a septate promycelium and terminal and lateral sporidia, sets at rest any doubts on this point.

2. Ustilago esculenta P. Hennings Hedwigia, 34 : 10, 1895 ; Miyabe, Bot. Mag. Tokyo, 9 : 197, 1895 ; Hori, Ann. mycol. Berl. 5 : 150, 1907 ; Yen, Ann. Cryptog. exot. 7 : 87, 1934 (Fig. 1)

In the hypertrophied tissues of the culms of *Zizania latifolia* (Griseb.) Turcz. Imphal (Manipur), Sept. 1940, leg. G. C. Gimson, comm. N. L. Bor (Fig. 1). Hennings, Miyabe and Zundel state that the spores are smooth but according to Hori and Yen, they are echinulate. Hori suggests that the spores of his specimen were echinulate because he examined a fresh specimen ; not only are the spores of the Imphal specimen echinulate but even those of the American specimen (Nov. 11, 1911, leg. Scofield) show echinulations under the oil immersion objective.

Fig. 1. Culms of *Zizania latifolia* affected by smut
a. Advanced case of attack
b. A culm recently attacked

3. Ustilago flagellata Sydow, Ann. mycol Berl. 9 : 144, 1911

Syn. *Sphacelotheca flagellata* Zundel, Bothalia 3 : 310, 1938.

In the ovaries of *Rottboellia exaltata* L.f. Anamalai (Madras), 18 January 1923, ex Herb. Coimbatore, No. 1321A. A columella is present but there is no true peridium ; the membrane covering the spores is made of host tissue.

4. Ustilago imperatae Mundkur sp. nov.

Sori penitus destruentes inflorescentiam, inclusi vagina atque cooperti membrana pallida nigra ; membrana postea flocculat, nigris pulverulentisque sporis expositis ; columella longorum frustulorum instar ; cellulae steriles nullae. Sporae ex sphaericis ad ovatas, nonnullae tenuiter angulares et ideo, ut videtur, triangulares ; quae in cellulà continentur granulata ; colore " natal brown " (Ridgway), diam. 13·0-18·7μ (med. 16·0μ) ; episporium crassum laeve ; germinatio per septatum promycelium lateralibus atque terminalibus sporidiis ornatum.

Typus legit N. L. Bor die 20 junii 1942 in inflorescentia Imperatae cylindricae Beauv. in loco Kohima, in montibus Naga, Assam.

Sori entirely destroying the inflorescence, enclosed by the sheath and covered by a greyish-black membrane made of host tissue ; membrane later flaking away revealing black, pulverulent spores ; columella in the form of long shreds ; no sterile cells. Spores spherical to oval, some slightly angular therefore appearing triangular, with granular contents, "natal brown" (Ridgway), 13·0—18·7μ in diameter with a mean of 16·0μ ; epispore 1μ thick, smooth ; germination by means of a septate promycelium with lateral and terminal sporidia.

In the inflorescence of *Imperata cylindrica* Beauv. Kohima, Naga Hills (Assam), 20 June 1942, leg. N. L. Bor (Type). *Sphacelotheca Schweinfurthiana* (Thuem.) Sacc. which is also on this host, is ovaricolous, its spores being minutely warty and 9·3 to 14·5μ in diameter. *Sphacelotheca nankinensis* Zundel also on this host has light reddish-brown, smooth spores with a diameter of 4-6μ.

5. Ustilago tragi Mundkur sp. nov.

Sori destruentes ovaria, turgidi, 5-8 mm. longi, 4-5 mm. lati, colore rubro-brunneo (mahogany), prominentes ex superioribus glumis involucralibus, atque cooperti densa membrana ; columella sterilesve cellulae nullae. Sporae globosae, subglobosae, vel elongatae ovatae, colore "cinnamon buff" (Ridgway), diam. 7·2—13·0μ (med. 10·4μ) ; episporium tenue, graciliter atque breviter echinulatum.

Typum legit P. V. Somayajulu die 24 novembris 1917 (ex herb. Coimbatorensi No. 969) in ovariis Tragi biflori Schult. (=Tragi racemosi Scop.), in loco Coimbatore (Madras).

Sori destroying the ovaries, swollen, 5 to 8 mm. long, 3 to 4 mm. broad, mahogany coloured, protruding out of the upper involucral glumes and covered by a thick membrane made of host tissue ; without columella or sterile cells. Spores globose, subglobose to elongate oval, "cinnamon buff" (Ridgway), 7·2 to 13·0μ in diameter (mean= 10·4μ) ; epispore thin with delicate and short echinulations.

In the ovaries of *Tragus biflorus* Schult. Coimbatore (Madras), 24 November 1917, leg. P. V. Somayajulu, ex Herb. Coimbatore, No. 969, (type).

6. Cintractia disvans Mundkur sp. nov. (Fig. 2)

Sori in basi rhachidis floralis, turgidi, circa 10-15 mm. longi, cooperti membrana brunnea ; membrana postea dehiscens, sporarum exposita nigra massa agglutinata et haud facile separabili. Sporae sphaericae ad ovatas, nonnullae tenuiter elongate ellipsoidaeae, colore "snuff brown" (Ridgway), diam. 8·9—13·2μ (med. 11·2μ) ; episporium ca. 1μ crassum, prorsus laeve.

Typum legit P. Maheshwari mense augusto 1940 in basi rhachidis inflores-centiae Caricis distantis Willd. (ex Kunth), in loco Dacca (Bengal).

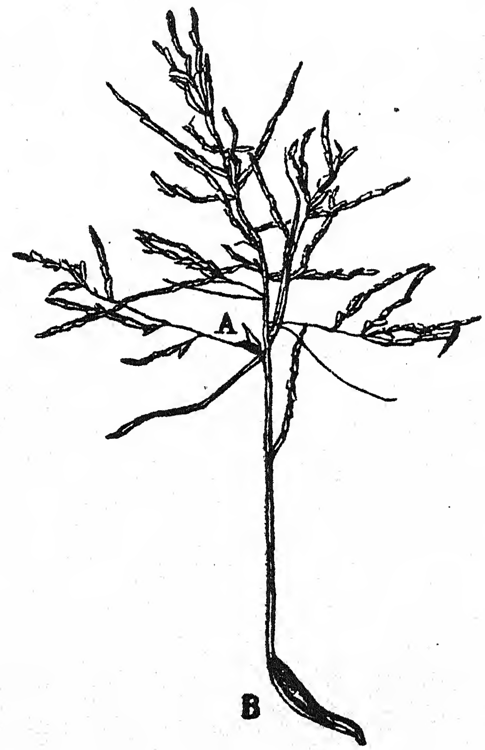

Fig. 2. Inflorescence of *Carex distans* attacked by smut. A and B, sori formed at the base of the rhachis

Sori at the base of the floral rhachis, swollen, about 10 to 15 mm. long, covered by a brownish membrane of host tissue ; membrane later dehiscing, revealing a black, agglutinated spore-mass, difficult to separate. Spores spherical to oval, some slightly elongate-ellipsoidal, "snuff brown" (Ridgway), 8·9μ to 13·2μ in diameter (mean= 11·2μ) ; epispore about 1μ thick, entirely smooth.

At the base of the rhachis of the inflorescence of *Carex distans* Willd. ex Kunth, Dacca (Bengal), August 1940, leg. P. Maheshwari (Type).

7. Sphacelotheca chloridis Mundkur sp. nov.

Sori destruentes omnia ovaria in inflorescentiae racemo, cooperti falsa membrana quae tandem flocculat, revelata sporarum massa brunneo-nigra, fere pulverulenta. Columella prominens, simplex ; cellulae steriles catervatim quinae ad denas coactae. Sporae sphaericae ad ellipsoidales, brunneae "Kaiser brown" (Ridgway), diam. 6·0—9·3μ, med. 7·2μ ; episporium minute echinulatum, tenue ; germinatio per septatum promycelium terminalibus atque lateralibus sporidiis ornatum.

Typum legit M. J. Thirumalachar in ovariis Chloridis barbatae Sw. in loco Bangalore (Mysore) die 20 augusti 1942.

Sori destroying all the ovaries in a raceme, covered by a false membrane which utlimately flakes away revealing brownish-black, almost pulverulent spore mass ; columella prominent, simple ; sterile cells in groups of five to ten. Spores spherical to ellipsoidal, "Kaiser brown" (Ridgway), 6·0 to 9·3μ in diameter (mean=7·2μ) ; epispore minutely echinulate, thin ; germination by formation of septate promycelium with terminal and lateral sporidia.

In the ovaries of *Chloris barbata* Sw. Bangalore (Mysore), 20 August 1942, leg. M. J. Thirumalachar (Type).

8. SPHACELOTHECA TRICHOLAENAE (P. Henn.) Mundkur comb. nov.

Syn. *Ustilago Tricholaenae* P. Hennings, Engler' bot. Jb. 17 : 3, 1893 ; Sydow, Svensk bot Tidskr. 29 : 67, 1935.

Sori entirely destroying the ovaries, all of which in a panicle attacked ; enclosed by a leathery, persistent, brownish-black, false membrane, dehiscing at the side, revealing dark brown, slightly pulverulent spore-mass ; columella prominent, simple ; sterile cells smooth, 12μ in diameter, in groups. Spores spherical, subspherical to ellipsoidal, "russet" (Ridgway), 7·1 to 10·8μ in diameter (mean = 8μ) ; epispore rather thick, minutely punctate.

In the ovaries of *Tricholaena teneriffae* Parlat, Sind, Comm. N. L. Bor (material is undated and exact locality in Sind is not stated). Hennings studied two specimens, the type collected in Arabia and another collected in Egypt ; the only other collection appears to be the one made in 1933 by G. Samuelsson in Palestine and identified by Sydow. Hennings states that the sori are 2-4 cm. long and 1 cm. broad but those of the Sind specimen are much smaller. In all other respects, it agrees with Hennings's description.

9. TOLYPOSPORIUM CYMBOPOGONIS Mundkur sp. nov.

Sori destruentes inflorescentiam, 2-4 cm. longi, 5·8 mm. lati, inclusi falsa membrana colore flavo-albida, persistente ; membrana dehiscens irregulariter, revelatis sporarum sphaericis massis nigris ; columella prominens, tenuis, simplex, aeque longa ac sorus vel paulisper longior ; sporarum massae subglobosae ellipsoidales vel irregulares, persistentes, haud facile resolutae in sporas, magnitudinis 29-83×25-62μ. Sporae peripherales sphaericae vel subsphaericae, tenuiter polygonales, minute echinulatae atque excavatae, brunneae "Kaiser brown" (Ridgway), diam. 6·5-11·2μ (med. = 8·6μ) ; interiores sporae polygonales laeve episporio coopertae, colorae clariori ; germinatio per septatum promycelium lateralibus atque terminalibus sporidiis ornatum.

Hab. in inflorescentia Cymbopogonis citrati Stapf, leg. M. J. Thirumalachar in loco Bangalore (Mysore), die decembris 1941.

Sori destroying the inflorescence, 2 to 4 cm. long and 5 to 8 mm. broad enclosed by cream coloured, persistent, false membrane, dehiscing irregularly revealing masses of black spore balls ; columella prominent, slender, simple, as long or slightly longer than the sorus ; spore balls subglobose, ellipsoidal or irregular, permanent, disintegrating into spores only with difficulty, 29-83×25-62μ. Spores at periphery spherical to subspherical, slightly polygonal, minutely echinulate and pitted, "Kaiser brown" (Ridgway), 6·5 to 11·2μ in diameter (mean=8·6μ) ; inner spores polygonal with smooth epispore and lighter colour ; germination by means of septate promycelium forming lateral and terminal sporidia.

In the inflorescence of *Cymbopogon citratus* Stapf, Bangalore (Mysore), 20 December 1941 leg. M. J. Thirumalachar (Type).

TILLETIACEAE

10. TILLETIA BRACHYPODII Mundkur sp. nov.

Ovaricola ; ovaria affecta haud leviter turgida, 10-25 mm. longa, 5-6 mm. lata, cooperta membrana plumbei coloris quae flocculat revelatis intus sporarum massis intense nigris atque tenuiter agglutinatis ; cellulae steriles magnitudine minores quam sporae, sphaericae, relative tenui pariete instructae. Sporae globosae vel subglobosae, brunneae 'hessian brown' (Ridgway), diam. 13·0-22·3μ (med.=16·9μ) ; episporium crassum, irregulariter verrucosum ; singulae sporae membrana evidenti atque hyalina obtectae. Germinatio post longum quietis periodum, formatis non-septato promycelio atque terminalibus sporidiis.

Typum legit K. M. Dutt in ovariis Brachypodii sylvatici Beauv. in loco Simla (Punjab), die 20 octobris 1942 ; idem, die 17 novembris 1941 ; Pushkarnath legit mense novembri 1942.

Ovaricolous ; attacked ovaries considerably swollen, 10-25 mm. long and 5-8 mm. broad, covered by an evanascent greyish-membrane which flakes away revealing deep-black, slightly agglutinated spore-masses within ; sterile cells smaller in size than spores, spherical, comparatively thin-walled. Spores globose to subglobose, "hessian brown" (Ridgway), 13·0 to 22·3μ diameter (mean=16·9μ) ; epispore thick with irregular verruculations ; each spore enveloped in an evident, hyaline membrane ; germination after a prolonged rest period by the formation of a non-septate promycelium and terminal sporidia.

In the ovaries of *Brachypodium sylvaticum* Beauv. Simla (Punjab), 28 October 1942, leg. K. M. Dutt (Type) ; also on 17 November 1941 ; November 1942, Pushkarnath. *Tilletia olida* (Reiss) Winter on *Brachypodium pinnatum* PB.

and *Brachypodium sylvaticum* is a leaf smut whose spores are 16 to 26μ in diameter. Comparison (Sydow *Ust.* No. 319) indicates that the two are different.

11. TILLETIA CARIES (DC.) Tulasne, Ann. Sci. nat. Bot. III, 7 : 113, 1847 ; Butler and Bisby, Sci. Monogr. Coun. agric. Res. India, 1 : 46, 1931

Syn. *Uredo caries* DC. Flore Fr. 6 : 78, 1815 *Tilletia Tritici* Winter, in Rabenhorst Kryptogamenfl. 1 : 110, 1881

In the ovaries of *Triticum vulgare* Host, New Delhi, April 1941, leg. B. P. Pal. This is the first authentic record of this bunt for the Indian plains. Seed, from which the crop at New Delhi was raised, appears to have come from Baluchistan. Apparently it was infected and conditions in Delhi may have been conducive for the crop to become slightly affected. This bunt is recorded for Sind by Uppal, Patel and Kamat but specimens are not available and its occurrence is doubtful.

12. TILLETIA FOETIDA (Wallr.) Liro, Die Ustilagineen Finnlands, 2 : 87, 1930

Syn. *Erysibe foetida* Wallroth, Fl. Cryptog. Germanie, 2 : 213, 1833. *Tilletia laevis* Kühn, in Rabenhorst Fungi europ. No. 1697, 1873. *Tilletia foetans* Trelease, Trans. Wis. Acad. Sci. Art. Lett. 6 : 139, 1886 ; Butler and Bisby, Sci. Monogr. Coun. agric. Res. India, 1 : 46, 1931

In the ovaries of *Triticum vulgare* Host, New Delhi, April 1941, leg. B. P. Pal. This appears to be the first authentic record of this fungus for the Indian plains. Seed came from Baluchistan and may have brought the infection. Specimens of this bunt recorded by Uppal, Patel and Kamat for Sind are not available and its occurrence there is doubtful.

13. TILLETIA KOELERIAE Mundkur sp. nov.

Sori destruentes ovaria, inclusi membrana plumbei coloris quae postea flocculat, revelata sporarum massa nigra ; ovaria affecta globosa vel ovata, tenuiter turgida, 4-8 mm. diam. Sporae pulverulentae, ovatae vel elongatae ellipsoidales, saepe irregulariter polygonales, brunneae " Brussel's brown " (Ridgway), diam. $16 \cdot 7$-$26 \cdot 0 \times 9 \cdot 3 \times 5\mu$, (med.$=20 \cdot 9 \times 18 \cdot 3\mu$) ; episporium crassum $1 \cdot 5$-$2 \cdot 5\mu$, dense minutissimis verrucis distinctum ; germinatio formato non-septato promycelio terminalibus sporidiis ornato.

Typum legit B. P. Pal in ovariis Koelariae cristatae Pers. in loco Simla (Punjab) die 21 maji 1942 ; materia collecta exigua.

Sori destroying the ovaries, enclosed by a greyish membrane which later flakes away revealing a black spore-mass ; attacked ovaries globose to oval, slightly swollen, 4 to 8 mm. in diameter. Spores almost pulverulent, oval to elongately ellipsoidal, often irregularly polygonal, " Brussel's brown " (Ridgway), $16 \cdot 7$-$26 \cdot 0 \times 9 \cdot 3$ 20.5μ in diameter with a mean of $20 \cdot 9 \times 18 \cdot 3\mu$ epispore $1 \cdot 5$ to $2 \cdot 5\mu$ thick, densely covered with very minute warts ; germination by formation of an unseptate promycellium forming terminal sporidia.

In the ovaries of *Koeleria cristata* Pers. Simla (Punjab), 21 May 1942, leg. B. P. Pal (Type, material scanty). Another species of *Tilletia* on this host is *Tilletia sterilis* Ule, whose sori occur in the form of long yellowish-grey stripes in the leaves. Its spores are reported to be smooth, and 20-30 × 18-24μ in diameter. Systematic position of *Tilletia sterilis* is in doubt for Massee (Kew Bulletin, 1899, p. 157) did not consider it to be as mut.

14. TILLETIA PENNISETINA Sydow, Ann. mycol. Berl. 27 : 421, 1929 ; Mundkur, Trans. Brit. mycol. Soc. 23 : 104, 1939

In the ovaries of *Pennisetum orientale* Rich. Simla Oct. 1942, leg. Pushkarnath

15. NEOVOSSIA INDICA (Mitra) Mundkur, Trans. Brit. mycol. Soc. 24 : 313, 1940

In the seeds of *Triticum vulgare* Host, New Delhi, 1942 ; Islamnagar (United Provinces) 1942 ; Mirpurkhas (Sind) 1941, leg. N. Prasad

16. ENTYLOMA BIDENTIS P. Hennings, in Engler's Pflanzenwelt Ostafrikas, etc. C. 5 : 49 1895

In the leaves of *Bidens pilosa* L. Bangalore (Mysore), 1 January 1942, leg. M. J. Thirumalachar

17. UROCYSTIS CARICINODES (Berk. and Curt.) Fischer de Waldh. Apercu Syst. Ustilagineen, p. 38, 1877

On stems and petioles of *Cimcifuga foetida* L. Gujmarg (Kashmir), June 1940, leg. A.N. Fotidar

18. UROCYSTIS STIPAE McAlpine, Smuts of Australia, p. 198, 1910 ; Clinton and Zundel, Mycologia, 30 : 281, 1938

In the leaves of *Stipa tortilis* Desf. Kohat (N.-W. F.P.) 1942

19. UROCYSTIS TRITICI Koernicke, Hedwigia 16 : 33, 1877 ; Butler and Bisby, Sci. Monogr. Coun. agric. Res. India, 1 : 42, 1931

On leaves of *Triticum vulgare* Host, Dindori, Mandla Dt. (Central Prov.), 1 January 1943, Deshpande. This is the first record of this smut for Central India.

SUMMARY

This paper reports the occurrence of 19 species of smuts hitherto unrecorded for India, of which seven are proposed as new species and one as a new combination. *Tilletia caries* and *Teilletia foetida* are reported from the Indian plains apparently for the first time. The range of occurrence of *Neovossia indica* and *Urocystis Tritici* has been widened, as the former is now reported to occur in the United Provinces and Sind, and the latter in Central India, in addition to the Punjab and the N.-W. Frontier Province.

FURTHER NOTES ON THE BIONOMICS OF *BEMISIA GOSSYPIPERDA* M. & L., THE WHITE-FLY OF COTTON IN THE PUNJAB

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(With four text-figures)

The white-fly of cotton has been recognized as a major pest in the Punjab and damages the cotton crop very seriously. Although it is not solely responsible for bringing about periodic failures of this crop in the Province, yet it plays a very important role as a contributive factor.

The life-history, bionomics, nature of damage and the control have been thoroughly studied and the results published separately. The present contribution, however, includes some additional data with respect to the items of bionomical interest studied during the course of these investigations.

The entire work was carried out at Lyallpur under the scheme financed by the Indian Central Cotton Committee. The scheme was originally sanctioned in 1931 for three years, but it was subsequently extended for a further period of two and a half years up to 30 September, 1936. The encouragement and generosity of the Committee is gratefully acknowledged.

The author is very much indebted to Khan Bahadur M. Afzal Husain for his guidance and valuable suggestions during the course of these investigations at Lyallpur, and for his criticisms while going through the manuscript.

The statistical analysis of the data was taken up by Mr Dwarka Nath Nanda, Assistant to the Cotton Research Botanist, Lyallpur. His help is highly appreciated.

Behaviour of the adults

The life-history of *B. gossypiperda* has been fully dealt with in a previous contribution [Husain and Trehan, 1933]. Further observations on this aspect of the problem, however, are discussed below:

i. *Sex proportion in nature*

Counts of about 8,000 adult white-flies from March to May yielded 22 per cent males. It may, therefore, be presumed that the overwhelming majority of females may be responsible to a great extent for excessive Parthenogenesis during that period.

ii. *Attraction to different colours*

Lloyd [1922] contributed on the colour tropism of *Avaporariorum*, and stated that both sexes were attracted to yellow traps. He further suggested that partial check might be devised by coloured traps. Observations, therefore, were made to study the relative attraction of *B. gossypiperda* adults, to various colours, and aqueous solutions of the following stains were tried : fuchsin (bright red), Cango red (blood red), eosin (orange red), picric acid (yellow), mythyl green (dark green), mythyl blue (blue), gentian violet (violet), pot. permanganate (purple), Orange G. (orange), pot. bichromate-light (light orange), yellow green (from the bazar) and water (colourless). Experiments were performed in a cage measuring 2×2× 1·5 ft. and lined with muslin at the sides as well as at the top. Lower 9 in. of the cage was covered with black-oil cloth to cut off the light in that region. Glass tubes of uniform size were filled with the coloured solutions and were hung against the inner walls of the cage at uniform distances from each other. Three such tubes were hung against each wall. Outer side of each tube was smeared with a transparent mixture of gloy and glycerine. Adults of cotton white-fly were collected in a glass chimney and were allowed to escape within the cage, one by one, through a small hole in the card board which was placed on the mouth of the chimney.

Observations were made from 11 A.M. to 4.0 P.M. daily and the captures recorded are shown in Table I.

The above data are further represented in Table II in the light of the percentage of attraction to various colours. It is obvious from these figures that the maximum attraction, on the whole, was noticed for yellow-green and yellow. Orange, blood red, blue and light orange were intermediate in this respect, whereas the colourless, bright red, orange red and purple attracted least. The position of the violet and dark green, however, was doubtful.

iii. *Range of flight*

Since *B. gossypiperda* continues to breed on a very large number of alternative hosts, both cultivated and wild, and practically throughout the year as shown by Husain, Trehan and Verma [1936] it is not possible to investigate the problem of the range of its flight unless a given locality is made absolutely free from this pest. In the circumstances, the best that could be done was to estimate the height to which these insects are

TABLE I

Relative attraction of B. gossypiperda *to various colours*

Colours	Captures under different observations						Remarks
	I	II	III	IV	Total	Average	
Yellow-green	227	112	29	31	399	99·8	Each colour was tried in N., S., E.,or West direction under different observations.
Yellow	120	34	144	30	328	82·0	
Orange	182	6	22	2	212	52·5	
Blood red	155	5	30	..	190	47·5	
Violet	177	1	11	..	189	47·3	
Blue	32	1	81	1	115	28·8	
Light orange	35	37	2	14	88	22·0	
Dark green	..	46	2	20	68	17·0	
Purple	..	58	3	5	66	16·5	
Orange red	4	7	18	..	29	7·3	
Colourless	10	11	..	..	21	5·3	
Bright red	9	10	..	1	20	5·0	
Total	951	328	342	104	1725		

TABLE II

Percentage of attraction to various colours

Colours	No. of observations				Average percentage of attraction
	I	II	III	IV	
Yellow-green	23·87	34·15	8·48	29·81	24·08
Yellow	12·61	10·37	42·10	28·84	23·48
Orange	19·13	1·83	6·42	1·92	7·33
Blood red	16·30	1·52	8·77	..	6·65
Violet	18·61	0·30	3·21	..	5·53
Blue	3·36	0·30	23·69	0·96	7·08
Light orange	3·68	11·28	0·59	13·46	7·25
Dark green	..	14·02	0·59	19·23	8·46
Purple	..	17·68	0·88	4·81	5·84
Orange red	0·42	2·13	5·26	..	1·95
Colourless	1·05	3·35	..	..	1·10
Bright red	0·94	3·05	..	0·96	1·24

capable of reaching. Therefore, some cotton seedlings which were grown in pots and kept free from the white-fly attack, were placed on the roof of the Agricultural College, and that of the College Hostel. The height of the roofs was approximately 40 ft. and the distance from the nearest cotton field was about 150 yd.

After a short exposure of a few days, adults and eggs of *B. gossypiperda* were recorded on these seedlings. It is, therefore, obvious that this insect is capable of reaching up to 40 ft. above the ground level and as the insect is very minute it is also expected that it may get carried long distances by wind. Presumably its distribution in localities where wind storms occur, may be very wide.

iv. Oviposition

(*a*) *Comparative oviposition on different regions of a plant.* Three plants each with three top, middle or bottom leaves were enclosed under a cage. For each observation 150 newly emerged adults of white-flies were introduced in the cage and the eggs laid on different leaves were counted after 24 hours. On an average, 51·5 per cent of the total eggs were laid on the top leaves, 46·7 per cent on the middle leaves and only 1·8 per cent on the bottom leaves. Field observations also confirmed these results as the highest number of eggs were found on the top leaves, and the number of eggs decreased as we proceed towards the base of the plant. In captivity, however, the eggs may be laid even on the stumps of defoliated seedlings, and may hatch, but the nymphs do not develop under these conditions.

(*b*) *Selection of leaf surface for oviposition.* In nature the eggs are invariably deposited on the lower surface of leaves. In captivity, however, a few eggs may also be laid on their upper surface. To ascertain whether this was the result of topographical position or the peculiar structure of the two surfaces or due to certain deeply placed behaviour of the pest, the following observations

were made : the leaf petiole was twisted in such a manner that the normal dorsal surface of the leaf became ventral and the leaf was held in this position. A known number of the adult white-flies was liberated on the leaf under muslin sleeves and a number of such experiments were performed. On an average, approximately 80 per cent of the eggs under observation, were laid on the natural lower surface even when it was turned upwards. It may be presumed that some structural peculiarities confined to the lower surface to which the adults are very sensitive, might be responsible for this behaviour.

(c) *Oviposition in relation to constant temperature.* The effect of some constant temperatures on oviposition was studied in incubators. No eggs were laid when the insects were kept at 19°C. Of the total number of eggs laid 0·2 per cent were laid at 21°C., 3·8 per cent at 24°C., 9.6 per cent at 27°C., 14.3 per cent at 30°C., 24·3 per cent at 33°C., 24·1 per cent at 35°C. and 23·6 per cent at 37°C., as shown in Table III. The temperatures

TABLE III

Oviposition under constant temperatures—May-June 1933

No of females liberated	Total number of eggs laid at—								Remarks
	19°C.	21°C.	24°C.	27°C.	30°C.	33°C.	35°C.	37°C.	
25	0	..	..	..	..	..	..	..	Observations at 19°C. taken only for 4 days and on 37°C. only for 5 days. Maximum egg laying was noticed between 33° & 37°C. and lowest at 21°C.
”	0	..	..	..	..	..	..	..	
”	0	..	..	..	..	..	..	..	
”	0	..	1	..	..	..	..	..	
”	..	..	3	..	..	..	..	..	
”	..	..	7	..	..	..	..	..	
”	..	..	..	..	..	..	65	19	
”	..	..	..	..	..	..	..	14	
”	..	..	..	..	..	..	51	24	
”	..	..	..	..	..	..	..	42	
”	..	..	..	..	..	144	..	27	
15	..	0	4	8	17	47	..	..	
”	..	1	6	9	13	22	19	..	
”	..	0	4	12	12	29	23		
”	..	0	3	14	16	23	21		
”	..	0	4	7	17	18	25		
10	..	1	..	..	14	17	20		
”	..	4	..	..	42	18	7		
12	..	..	..	..	8	39	30		
”	..	0	..	..	24	..	15		
10	0	0	..	..	19	30	18		
”	..	0	..	..	6	19	..		
”	..	0	2	..	5	6	5		
”	..	0	..	..	14	..	..		
”	..	0	5	..	..	..	..		
”	..	1	2	6	11	25	..		
”	..	0	1	10	12	..	..		
”	..	0	2	4	7	..	..		
”	..	0	4	10	14	8	..		
”	..	0	2	3	7	20	..		
”	..	0	8	17	22	10	..		
”	..	0	4	8	10	31	..		
”	..	0	4	9	8	13	..		
15	..	0	3	7	13	11	..		
10	..	0	7	11	17	17	..		
15	..	0	9	13	18	20	..		
”	..	0	5	7	14	25	..		
”	..	0	11	16	25	20	..		
”	..	0	6	15	25	31	..		
”	..	0	4	11	15	17	..		
”	..	0	5	11	20	15	..		
”	..	0	12	17	7	24	..		
15	..	0	2	5	15	35	..		
”	..	0	5	18	23	21	..		
”	..	0	..	..	..	32	..		
Totals		7	135	248	489	777	309	126	
Average No. of eggs per observation	0	0·2	4·1	10·3	15·3	25·9	25·9	25·2	
Percentage of egg laying at different temperatures	0	0·2	3·8	9·6	14·3	24·3	24·1	23·6	

ranging from 33°C. to 37°C., therefore, were most suitable. This fact provides explanation for the phenomenon that the most active period for multiplication of the pest is during May to September, when the average maximum temperature ranges from 33°C. to 41°C.

Relative incidence on different varieties of cotton

Since various varieties of cotton are under cultivation in the Punjab the varietal susceptibility and relative preference by the pest, was considered to be a valuable problem. It is presumed that our knowledge about the varietal susceptibility or resistance, may ultimately help in determining the control of the pest, firstly by encouraging the resistant varieties and secondly by combating the pest at the right time when its activity is well pronounced on a particular crop.

It has already been pointed out by Husain and Trehan [1933] that the white-flies are no respectors of varieties and that both *desi* and American varieties are attacked although the incidence of attack differs according to the season. This view is further supported by the observations made during the five years when these investigations were in progress.

During 1931-33, *mollisoni* and 4F. as representatives of *desi* and American cottons respectively were compared. *Desi* varieties on the whole, are comparatively more infested during the growing period, till about the end of August. After that, the infestation, as a rule, declines considerably on all the varieties but the attack is relatively higher on the American types (Fig. 1). Towards the end of the season, however, the attack increases once again, on the *desi* varieties, as new leaves sprout and the pest is attracted to them.

During 1934 and 1935, some of the new selections of American cottons were compared with the *desi* type *mollisoni* and the American types 4F and 289F (Table IV). The incidence of white-fly attack was extremely low during both the years, but the relative attack on different varieties followed almost the same cycle as previously observed—at first *mollisoni* showed a relatively higher attack than any of the American types in both the years, but during September and October in 1934 and later half of August and early September in 1935, the infestation increased relatively on some of the American strains namely 4F and L.S.S. Towards the end of the season, however, the attack again increased on *mollisoni* (Fig. 2).

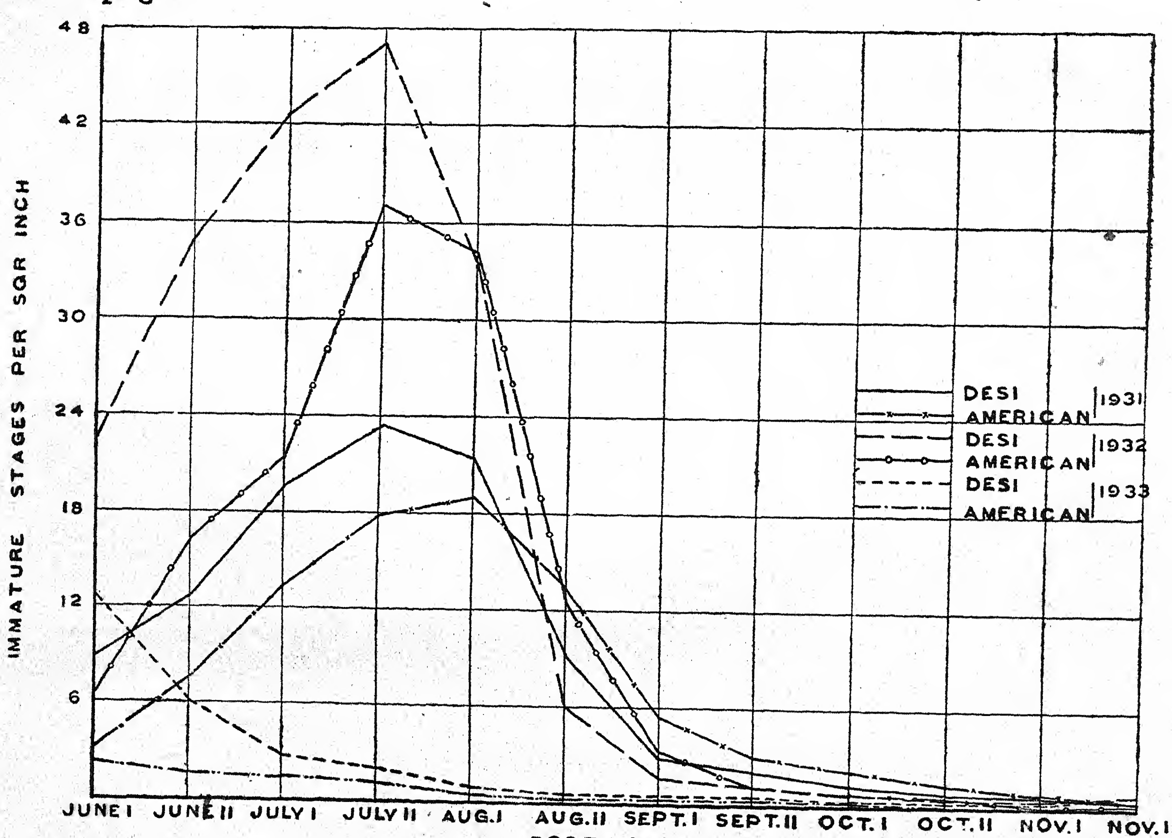

Fig. 1. Relative infestation of *B. gossypiperda* on different varieties of cotton (*desi* and American) 1931-33

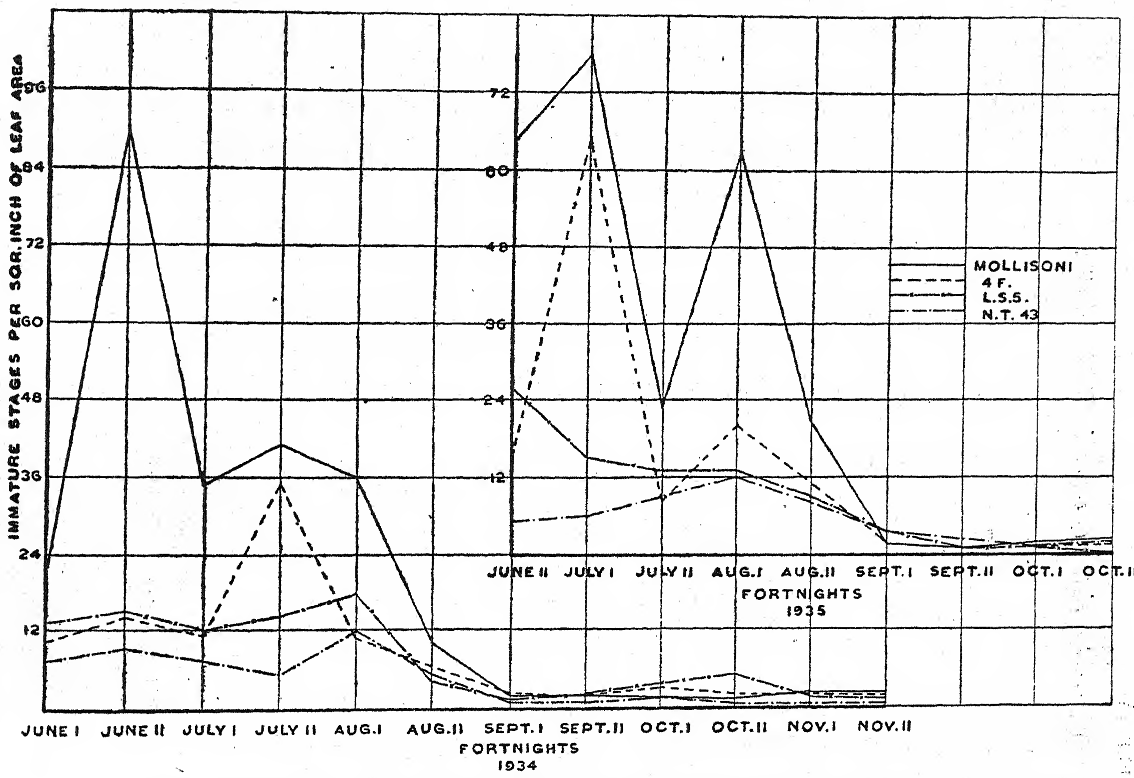

FIG. 2. Relative incidence of *B. gossypiperda* attack on different varieties of cotton in 1934 and 1935

Taking the entire season the white-fly attack on *desi* cotton was significantly higher than on the American cottons during both the years. The attack on American cottons, however, did not differ significantly as well as in the order of significance as shown in Table V. As is obvious from the data given above, of the relative attack on American varieties the severest infestation was noticed on 4 F against the least attack on N. T. 43 (Fig. 2), since the figures for N. T. 38 have not been considered due to irregular observation during 1935.

To determine the causes for the change-over of the relative infestation from *desi* to American varieties and *vice versa*, observations were made on (1) variations in the pH values of cell sap in *desi* and American varieties and (2) their moisture contents.

(1) Some insects show a degree of preference for certain hosts during different seasons. According to Jackson [1934] this phenomenon is probably brought about by the condition of the sap, which represents the physiological state of the plant. Acidity being an index of this change pH, reactions of the two common varieties namely, *mollisoni* and 289F. representing the *desi* and American types respectively were studied when grown under identical conditions.

The investigations carried out in this connection have shown that the pH gradients from top to bottom leaves of a plant varied with its age. The differences were not so marked in the very early stage of growth, but later on the pH increased from top to bottom. Towards maturity, however, these variations became erratic and the top leaves in *desi* and the middle ones in general showed the highest pH. Similar gradients in pH have also been observed by Hass [1920], Gustafson [1924] and Mukerji [1928].

The range of variations in the pH value of leaves from the different regions of a plant under observation, is shown in Tables VI and VII.

During 1932, when white-fly infestation was high on both the varieties, the pH values for 289F, were on an average, slightly lower than those of *mollisoni* till the end of June. After this they equalized or those of 289F increased slightly. During August the values again increased in the *desi* variety and the differences widened as the plants reached maturity. The incidence of white-fly attack corresponded with the trend of the pH curve indicating partiality towards higher values, and therefore, was suggestive of some correlation with the reaction in the plant juice. The infestation, however, was not affected immediately

TABLE IV

Relative incidence of B. gossypiperda *attack on different varieties of cotton in 1934 and 1935*

Year and month	Fortnight	*Mollisoni*			4F			289F			L. S. S.			N. T. 38					
		Leaf area examined	Immature stages	Infestation per sq. in.	Leaf area examined	Immature stages	Infestation per sq. in.	Leaf area examined	Immature stages	Infestation per sq. in.	Leaf area examined	Immature stages	Infestation per sq. in.	Leaf area examined	Immature stages	Infestation per sq. in.	Leaf area examined	Immature stages	Infestation per sq. in.
1934																			
June	I	38·09	87	2·28	28·27	28	0·99	28·86	22	0·76	36·83	48	1·30	24·03	30	1·24	32·34	24	0·74
	II	100·64	901	8·97	97·31	135	1·38	92·38	73	0·79	91·01	133	1·46	86·40	30	0·34	76·67	66	0·86
July	I	75·19	261	3·47	199·58	229	1·14	146·67	61	0·41	151·50	186	1·23	245·52	83	0·33	232·23	151	0·65
	II	327·92	1339	4·08	270·98	958	3·53	391·74	558	1·42	457·85	634	1·38	278·99	143	0·51	463·75	243	0·52
August	I	492·75	1753	3·55	1313·57	1398	1·06	936·96	1110	1·18	746·08	1359	1·82	1008·28	503	0·49	886·76	1079	1·21
	II	536·19	512	0·95	1736·12	795	0·62	924·63	189	0·20	969·39	400	0·41	901·99	266	0·29	971·39	486	0·50
September	I	573·32	82	0·14	1808·92	295	0·16	1580·84	113	0·07	1192·62	94	0·07	897·47	71	0·07	1284·50	63	0·05
	II	727·69	95	0·13	1722·72	231	0·13	2153·27	260	0·12	1854·50	307	0·16	1199·34	114	0·09	1035·33	51	0·04
October	I	771·37	84	0·11	1689·31	437	0·26	1603·54	160	0·09	1380·49	449	0·32	1103·25	199	0·18	1027·09	101	0·09
	II	389·40	34	0·08	630·03	99	0·16	805·82	47	0·05	511·93	266	0·51	821·97	92	0·11	602·33	7	0·01
November	I	824·22	129	0·15	1698·46	225	0·13	1550·42	133	0·08	1659·44	170	0·10	1580·95	90	0·05	634·09	71	0·11
	II	402·41	66	0·16	1139·38	138	0·12	889·26	132	0·14	895·66	85	0·09	691·73	108	0·15	743·68	100	0·13
Av. Inf. per sq. in. during the season				2·006			0·807			0·443			0·738			0·321			0·409
1935																			
June	II	158·07	1022	6·46	140·08	204	1·45	138·86	296	2·24	181·23	470	2·59	197·51	328	1·61	240·24	132	0·54
July	I	218·31	1705	7·81	265·61	1715	6·46	262·71	899	3·42	293·98	430	1·46	...	...	...	351·94	195	0·55
	II	803·25	1820	2·26	877·13	736	0·83	679·54	928	1·36	950·36	1211	1·27	838·38	874	1·04	960·11	896	0·93
August	I	1252·83	7859	6·27	2478·27	5031	2·03	2274·69	5002	2·19	3022·99	3844	1·26	1998·73	3488	1·74	2203·36	2581	1·17
	II	1034·72	2133	2·06	1608·53	1818	1·13	1778·45	1036	0·51	2062·59	1888	0·90	1457·69	1355	0·09	1539·55	1237	0·80
September	I	1051·63	162	0·16	2912·76	483	0·16	2480·20	640	0·24	2896·26	828	0·28	1083·62	294	0·27	2226·28	615	0·27
	II	980·03	64	0·06	1294·89	110	0·08	1162·33	150	0·12	1269·89	128	0·10	...	...	...	869·47	167	0·19
October	I	337·91	44	0·13	529·03	38	0·06	733·67	84	0·11	744·67	48	0·06	...	...	...	541·71	48	0·08
	II	621·34	113	0·18	976·65	116	0·11	1205·28	133	0·11	1273·75	41	0·03	...	...	...	732·01	91	0·12
Average				2·281			1·368			1·153			0·883			0·950			0·517

Table V

Analysis of variance

Variance due to (or S. V.)	1934 D. F.	1934 S. S.	1934 M. S.	1934 F.	1935 D. F.	1935 S. S.	1935 M. S.	1935 F.
Dates of observations . .	11	43·1026	3·9184	..	8	79·7477	9·9685	..
Varieties	5	23·6057	4·7211	4·545**	4	28·0384	7·0096	4·298**
Error	55	57·1318	1·0388	..	32	52·1935	1·6310	
Total .	71	123·8401	..	..	44	159·9796	..	

Average values of infestation

—	S. E.	Sig. diff.	Moll.	4 F	L. S. S.	289 F	N. T. 43	N. T. 38
1934		0·848	2·006	0·807	0·738	0·443	0·409	0·321
1935		1·234	2·821	1·368	0·883	1·153	0·517	..

Relative attack of white-fly

(Order of significance)

1934 . . .	Moll.	4 F	L. S. S	289 F	N. T. 43	N. T. 38
1935 . . .	Moll. .	4 F	289 F	L. S. S.	N. T. 43	

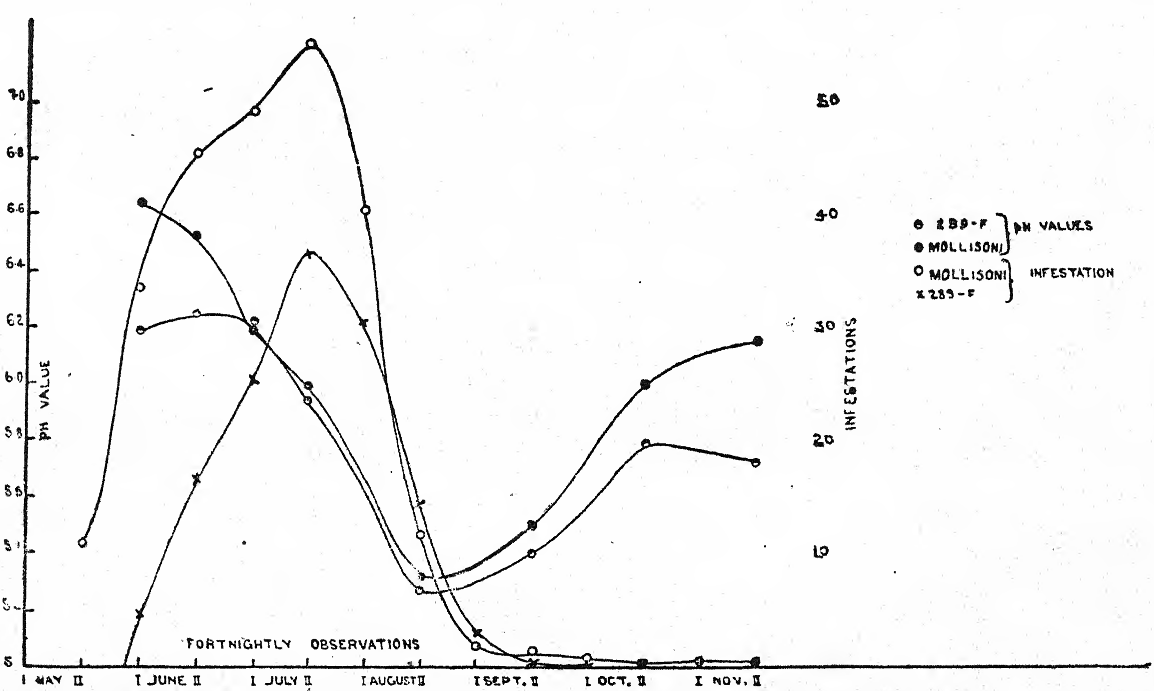

Fig. 3. White-fly infestation and pH values of varieties of cotton in 1932

but there was a certain amount of lag and the insect attack did not fall exactly when the *p*H curve went down. This is not contrary to expectation because the nymphs being fixed on the leaves, could not move and it must take some time before the effect of the change in *p*H can be appreciated by the insects feeding on the sap.

During 1933, the incidence of white-fly attack in general was quite insignificant throughout the season and the *p*H values of the leaf sap were correspondingly low. This opens up a fruitful line of attack on this pest. Variations in *p*H might be responsible for relative immunity of varieties and control of seasonal multiplication of certain pests be affected by changing this value. Hence the possibility of preventing attack of sucking insects through soil treatment.

(2) During 1934 and 1935 preliminary observations were made to stu dy if any correlation existed between the incidence of white-fly and the amount of moisture in the leav es of various types of cotton. The data with regard to the moisture are presented in Table VIII, whe reas the relative infestaticns have been taken into account from Table IV as summarized under for tnightly intervals. Of all the types under observ ation *mollisoni* had the least percentage of mois ture while 4F had the maximum.

TABLE VI

Range of variations in pH *of different leaves of a cotton plant*

Month	1932		1933	
	289-F	*Mollisoni*	289-F	*Mollisoni*
June	6·28—6·41	6·19—6·90	5·34—5·48	5·30—5·60
July	5·59—6·49	5·79—6·47	5·30—5·55	5·42—5·63
August	5·19—5·31	5·16—5·42	5·25—5·68	5·30—5·88
September	5·25—5·55	5·25—5·95	5·30—5·60	5·12—5·63
October	5·20—7·50	5·40—7·50	5·42—6·29	5·38—6·13
November	5·30—6·95	5·45—7·10	..	..

Because of these variations, the mean of the *p*H values of all the leaves was taken for comparison. These results are given in Table VII and the values for 1932 have been plotted in Fig. 3.

TABLE VII

Relative incidence of B. gossypiperda *attack on* mollisoni *and 289F cottons and the* pH *value of the respective cell sap*

Fortnight	1932				1933			
	Mollisoni		289-F		*Mollisoni*		289-F	
	Infestation per sq. in. of leaf area	*p*H value	Infestation per sq. in. of leaf area	*p*H value	Infestation per sq. in. of leaf area	*p*H value	Infestation per sq. in. of leaf area	*p*H value
June I	36·00	6·64	4·67	6·19	8·03	..	1·17	..
II	45·66	6·53	20·36	6·25	1·14	5·41	1·07	5·41
July I	48·19	6·19	25·22	6·22	2·73	5·57	1·01	5·43
II	55·70	5·94	37·45	5·95	1·67	..	0·98	..
August I	39·97	..	35·60	..	0·50	5·65	0·52	5·53
II	9·32	5·32	11·22	5·27	0·35	..	0·10	..
September I	1·72	..	3·06	..	0·28	..	0·16	..
II	1·03	5·50	0·23	5·39	0·32	5·42	0·14	5·42
October I	0·58	..	0·38	..	0·12	..	0·13	..
II	0·30	6·08	0·26	5·80	0·14	5·67	0·09	5·75
November I	0·48	..	0·13	..	0·30	..	0·15	..
II	0·48	6·16	0·20	5·74	0·57	..	0·13	..

TABLE VIII

Relative amount of moisture in the foliage of different varieties of cotton

Variety of cotton	1934				1935				
	Percentage of moisture on				Percentage of moisture on				
	6·VII	20·VII	2·VIII	Average	21·VI	27·VII	13·VIII	6·IX	Average
Mollisoni	71·7	75·2	73·4	73·4	78·0	77·1	75·6	72·7	75·9
4F	79·2	79·9	80·2	79·8	83·0	81·6	80·2	76·9	80·4
289F	79·0	77·8	80·6	79·1	83·4	80·6	79·7	78·1	80·5
L. S. S.	74·1	79·8	78·9	77·6	82·1	78·7	77·2	75·1	78·3
N. T. 38	78·2	79·6	79·7	79·2	82·6	79·3	77·9	75·3	78·8
N. T. 43	78·2	79·5	78·2	78·6	82·5	80·4	79·5	75·2	79·4

These observations have not shown very strict relationship between the percentage of moisture and the white-fly attack on different varieties. The only conclusive statement that can be offered in this connection is, that *mollisoni* with lowest percentage of moisture was highly infested. These results support the observations in the fields in so far as the restricted irrigations have yielded comparatively higher white-fly attack as is shown below.

Incidence of white-fly attack in relation to the amount of water applied to cotton crop in the fields

Insect behaviour towards crops depends on various factors and soil moisture may be one of them. Mumford [1925] put forth an hypothesis that a disturbed water content from whatever cause rendered the cotton plant more susceptible to the attack of sap feeding insect pests such as thrips. In California thrips have never been found in large numbers on cotton plants receiving optimum water supply whereas those suffering from shortage of water have been found to be more attractive. This statement also receives support from Bedford [1921] with his observations on *Heliothrips indicus* Bagnell, on Egyptian cotton in the Sudan. Withycomb [1926] has also found it true in the case of sugarcane frog hopper, *Tomaspis saccharina* Dist. Wardle [1927] states that the plants receiving excessive water supply have a relatively lower infestation of *Thrips tabaci* Lind than those receiving sufficient supply, while, those receiving the minimum water supply have a relatively higher attack than those receiving normal irrigation. Lees [1926], on the other hand, maintains that heavy irrigation and heavy rainfall resulted in increased susceptibility to berseem aphis, *Trifolium alexandrium*. It is obvious, therefore, that different insects behave differently in this respect.

To determine the behaviour of *B. gossypiperda*, however, observations were carried out in the watering experimental plots of the Cotton Research Botanist, at Risalewala. Seven to nine types differentiated into 5-6 sets according to the number of irrigations, were under observation. The range of variation in the number of irrigations in the respective sets was 3-7 in 1931, 4-10 in 1932, 3-7 in 1933 and 4-9 in 1934. The total amount of water applied to various sets, therefore, varied from 8·96 to 20·83 in.; 18·81 to 36·05 in.; 8·99 to 26·90 in.; and 12·01 to 26·92 in. respectively. Relative incidence of *B. gossypiperda* in different sets was estimated at fortnightly intervals. Average number of immature stages of the pest, per square inch of leaf area, was worked out from 2-4 replications of the plots under each treatment and the data are summarized in Table IX.

The data presented above have shown that type IV which received the largest number of irrigations and consequently, the maximum amount of water throughout these investigations had, on an average, the lowest white-fly attack. On the other hand, types III during 1931 and 1932, VII during 1933 and III, VIII and IX during 1934, which received restricted irrigations and therefore the minimum supply of water, were comparatively severely infested (Fig. 4). Although the white-fly infestation in general w s extremely low during 1933 and 1934, as compared to that in the first two years, still the trend of the relative attack in the respective types was practically the same. Thus it may be presumed that abundant water supply to cotton crop lowers the white-fly infestation to a considerable extent whereas reduced water supply increases the susceptibility for attack. The data were analysed statistically and their results are given below:

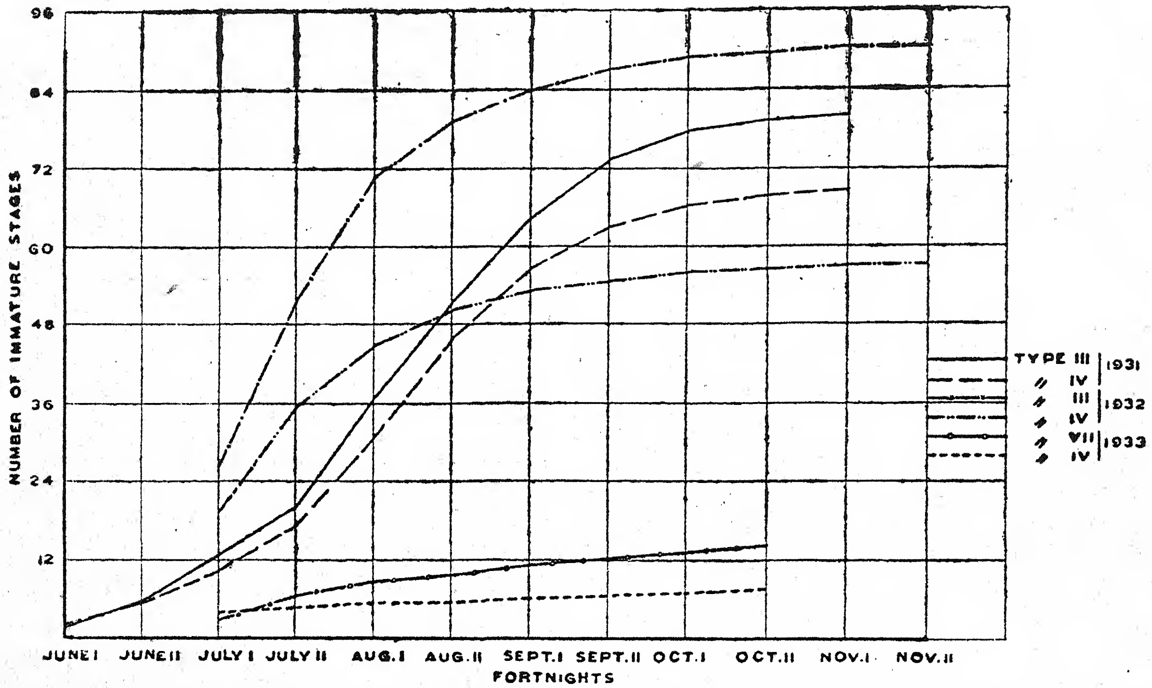

FIG. 4. Comparative infestation of *B. gossypiperda* in relation to the maximum (Type IV) and minimum (Types III and VII) number of irrigations applied to cotton crop —1931-33

TABLE IX

Relative incidence of B. gossypiperda *in relation to the amount of water applied in the fields—1931-34*

Year	Type No.	No. of irrigations given	Total amount of water applied (acre in.)	Total leaf area examined (sq. in.)		Average infestations per sq. in.
1931	IV	7	20·83	792	Observations on each leaf were made within an area of 1 sq. in.	6·28
	I & VI	6	17·85	1584		6·66
	VII	5	15·14	792		6·97
	II & V	4	11·75	1584		6·72
	III	3	8·96	792		7·25
1932	IV	10	36·05	5688·81		4·77
	VI	8	29·81	5122·19		6·18
	I & V	7	26·87	11167·50		6·34
	VII	6	23·95	5242·78		6·62
	II	5	21·09	5650·96		7·80
	III	4	18·82	5490·00		7·40
1933	IV	7	26·90	4076·05		0·68
	I	6	18·05	3988·06		1·05
	VI	5	14·82	4297·45		0·93
	II, III, V . .	4	12·03	12160·87		1·26
	VII	3	8·99	4203·52		1·55
1934	IV	9	26·92	3586·02		0·67
	VI	8	24·00	3480·64		0·95
	V	7	20·96	3493·01		0·84
	I, VII	6	17·92	7054·05		0·70
	II	5	15·06	3655·33		0·86
	III, VIII, IX .	4	12·01	10606·09		1·22

The correlations between the amount of water and the incidence of attack as given in Table IX were worked out for all the four years and the values obtained were —0·860 ; —0·958 ; —0·906; and —0·653 for N = 5 ; 6 ; 5 and 6 for the years 1931, 32, 33 and 1934 respectively. The correlation in all the cases was high and negative being significant in 1932 and 1933. This shows that an increased amount of water depressed the white-fly attack. Since a cultivator understands more in terms of the number of irrigations than the amount of water applied to his crop, therefore, the four types of irrigations, i.e. 4, 5, 6, and 7 which were common in all the years were compared and the average infestation per sq. in. ranged as 4·15, 4·14, 3·76 and 3·53 with a standard error of $\pm 0 \cdot 153$. The trend was linear and the number of irrigations on the whole differed significantly, there being no significant difference between 4, 5, and 6 irrigations and between 6 and 7. From this it may easily be concluded that 6 or 7 irrigations are needed in order to suppress the white-fly attack significantly.

INCIDENCE OF WHITE-FLY ATTACK UNDER DIFFERENT CONDITIONS OF CULTIVATION

A. *Pit and line sown.* This experiment was conducted during 1934, by the Deputy Director of Agriculture, Lyallpur. Cotton was sown in a few plots in lines as usual while in others alternating to those, it was sown in pits which were 5 ft. apart from each other and were filled up with farmyard manure before sowing. Each of these pits had a single cotton plant and the rest of the agricultural operations were uniform in both the sets. The plants grown in pits were very bushy evidently because of the larger space and excessive manure. The relative white-fly attack was worked out weekly on the respective sets and the crop sown in pits showed, on an average, comparatively lower attack as shown in Table X.

TABLE X

Relative infestation of B. gossypiperda *on crop sown in pits and in lines*

Time—Fortnightly	Pit sown		Line sown	
	Leaf area examined	Average infestation per sq. in.	Leaf area examined	Average infestation per sq. in.
July I	526·40	0·78	500·90	4·00
II	396·10	2·09	489·52	6·40
August I	1066·69	0·72	1095·12	1·70
II	948·89	0·27	933·05	0·71
September I	1036·10	0·28	966·75	0·38
II	467·29	0·05	529·69	0·16
October I	831·03	0·14	724·40	0·29
II	760·65	0·22	802·09	0 36

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STUDIES IN SOIL DISPERSION

I. DISPERSION OF SOILS BY MECHANICAL METHODS

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Mechanical methods of soil dispersion were largely used in the beaker method of mechanical analysis of soils, where maximum dispersion in single operation is not necessary. The advent of the pipette methods brought into prominence the entire question of soil dispersion. It was soon realized that the mechanical methods failed to bring about complete dispersion. The use of chemicals not only ensured maximum dispersion, but the technique could be standardized much more efficiently than was the case with mechanical methods.

Among the purely mechanical methods of dispersion one of the oldest is boiling which is probably still used in certain laboratories and its use in electrolyte free suspensions may be justified. Comparatively recently Nostitz [1926] endeavoured to obtain the effect of 'cold boiling' by drawing air through the suspension and thus obviate the objectionable features of heating. Simple rubbing in water with a stiff brush or rubber pestle was another early procedure used by Beam [1911]. Whittles [1924] used a vibrating machine to disperse soil samples and Olmstead [1931] used supersonic waves for the purpose. The supersonic vibrations were produced by a piezo-electric quartz crystal immersed in an oil bath. The energy was transmitted through the oil into an Erlenmeyer flask containing a water suspension of the soil. The arrangement, however, is far too costly to justify its use for routine purposes especially as the results are practically the same as those obtained by rubbing with a rubber pestle. Bouyoucos [1927] used an electric drink mixer to disperse his samples. This procedure was slightly modified by Baver [1928].

The use of chemicals such as sodium carbonate or ammonia to aid dispersion by shaking was advocated by Briggs, Martin, and Pearce as early as 1904. Although the nature of the chemicals used has differed in the hands of different workers, this simple procedure still remains the most widely used standard method of dispersion. The advisability of using chemicals has always been the subject of heated discussion and opinion is still divided on this question. Several workers have passed judgment in favour of one or the other method. The main difficulty has been the lack of an absolute standard for reference. Modern physico-chemical methods of dispersion aim at maximum dispersion as evidenced by the highest yield of clay and thus can provide an absolute standard for comparison. It has been shown by Puri and Manohar Lal [1938] that provided the only exchangeable ion in a soil is Na or Li and its pH value not less than 10·8 its dispersion is at its maximum, and the yield of clay the highest. It is quite immaterial how this condition is brought about experimentally. For instance, we can directly shake it with the requisite amount of NaOH or LiOH, if it is a hydrogen soil; on the other hand, if it is a Ca-soil, we can convert it into a H-soil by dil. HCl treatment and then shake it with NaOH or LiOH [Puri and Amin, 1928], or we can precipitate the exchangeable Ca by treatment with ammonium carbonate [Puri, 1935] or sodium carbonate or oxalate [Puri, 1936] or we can replace the exchangeable Ca by Na by treatment with NaCl [Puri, 1929]. Provided that in every case we make sure that the soil has been finally brought to pH 10·8, the results are the same whatever method is used. This result is very important and should go a long way in providing a fundamental basis for the large number of apparently arbitrary methods of dispersing soils for mechanical analysis of soils. This generalization by defining the final stage of dispersion will greatly help in overcoming the natural reluctance of workers, versed in one method to adopt another. Since this final stage can be brought about in several ways, it is immaterial which method we use as long as we remember the conditions under which maximum dispersion is obtained. Having enunciated this fundamental principle, we can examine the purely mechanical methods of dispersion with greater confidence. It must be remembered that the dispersion of soil colloids is largely a question of overcoming the cohesion between the particles. Physico-chemically it is brought about in a medium of pH 10·8 with Na or Li ions when the cohesion under water is minimum. Physically the choice must fall on one or more of the half a dozen methods referred to in the foregoing.

Experimental

The choice of a H-soil for the preliminary experiment is obvious in view of the fact that it is the starting point for the gradual introduction

of bases. Not only it is the most important basic material for all soil studies, but its use is particularly appropriate in this case as the internal cohesion is probably the highest and if a mechanical treatment is successful in this case, the efficiency of the method for all types of soils will be assumed. Besides, a H-soil is often required at maximum dispersion for several physico-chemical measurements. This object can be accomplished by converting it first into a Na-soil at *p*H 10·8, and then reconverting it to a H-soil without allowing it to dry. This procedure is tedious and it is not certain if this double treatment does not produce any material changes in the soil. A straight-forward mechanical dispersion would be far superior for fundamental studies of this nature. For comparing the various mechanical methods of dispersion such treatments which require elaborate mechanical contrivances were left out of consideration, for it was felt that unless a physical method could be made at least as simple as the admittedly efficient chemical treatments, it would not find favour generally from the practical point of view.

The following methods were tried :

(*1*) Boiling, both 'cold' and hot and with sand.

(*2*) Rubbing with rubber pestle.

(*3*) Simple shaking in a mechanical shaker with and without rubber balls or sand.

These are dealt with under separate heads. A black cotton soil was used in the first instance. It was freed from bases by the usual *0·05 N.* HCl treatment and air dried. The maximum clay percentage in the soil was 55.

(*1*) *Boiling*

Boiling was done for varying lengths of time with varying amounts of water. The technique for 'cold boiling' constituted in drawing a current of air through a sintered glass Buchner funnel. The results are given in Table I.

TABLE I

Dispersion of a H-soil (containing 55 per cent of clay) by boiling

(10 gm. of the soil taken)

..	Clay per-cent	Remarks
Boiling for 30 min. with 100 c.c. of H_2O	21·5	
Boiling for 30 min. with 200 c.c. of H_2O	20·4	Effect of volume is thus nil
Boiling for 30 min. with 300 c.c. of H_2O	22·1	
Boiling for 30 min. with 400 c.c. of H_2O	22·1	
Boiling for 15 min. with 200 c.c. of H_2O	18·5	
Boiling for 1 hour with 200 c.c. of H_2O	25·3	
Boiling for 2 hours with 200 c.c. of H_2O	32·1	
Boiling for 4 hours with 200 c.c. of H_2O	36·2	
Boiling for 4 hours with sand	37·4	
'Cold boiling' for 30 min. with 50 c.c. of water	3·6	As compared to boiling dispersion is very little
'Cold boiling' for 30 min. with 25 c.c. of water	3·5	

It will be seen that boiling does not seem to be an efficient method of dispersion. Even the highest clay, i.e. 37·4 per cent obtained by 4 hours' boiling is much below the maximum of 55 per cent which this soil contains. It is surprising that the so-called 'cold boiling' is the least helpful. It was believed that the presence of sand might help in the breaking up of the aggregates. It seems that though this gives a slightly higher yield of clay the difference is not very significant.

(*2*) *Rubbing with rubber pestle*

Rubber pestle was the usual rubber bung attached to a stout glass rod. Rubbing with the band besides being tiring is not effective as will be seen from Table II. A rubber pestle attached to a motor that was made to rotate in an agate mortar held in the hand and pressed lightly against the pestle proved very effective. The maximum clay was obtained in half an hour.

TABLE II

Dispersion of a H-soil (containing 55 per cent of clay) by rubbing with a rubber pestle

(10 gm. of the soil was taken)

	Clay per cent (0·002 mm.)
Rubbed in an agate mortar with the rubber pestle by hand with 10 c.c. of water for	
5 minutes	6·0
10 minutes	16·0
15 minutes	14·2
30 minutes	24·6
Rubbed in an agate mortar with a mechanically rotated rubber pestle with 10 c.c. of water for	
5 minutes	38·0
10 minutes	44·8
15 minutes	47·2
20 minutes	52·2
30 minutes	55·6
Rubbed for 30 minutes as above with	
20 c.c. of water	48·0
30 c.c. of water	44·9
40 c.c. of water	42·8

It will also be seen that the amount of water used has an important bearing on the success of this method. When the amount of water is increased from 1 : 1 ratio the soil particles have a tendency to float and thus escape the grinding action of the pestle.

(3) Shaking in a mechanical shaker

A mechanical shaker is the simplest and most widely used contrivance for the dispersion of soil. Its effectiveness can be enhanced by the addition of rubber balls or sand to the suspension. Shaking the suspension with sand gave the highest yield of clay as will be seen from Table III.

TABLE III

Dispersion of a H-soil (containing 55 per cent of clay) by mechanical shaking

(10 gm. of the soil was taken)

Time of shaking	Addition to suspension	Clay per cent
24 hours	Nil	22·9
24 hours	10 Rubber balls . . .	15·3
24 hours	20 rubber balls . . .	18·6
24 hours	50 gm. of coarse sand . .	52·8
24 hours	50 gm. of fine sand . .	42·1

Maximum dispersion with sand is attained by shaking for 24 hours using a soil-sand ratio of 1 : 5. Neither the temperature nor the volume of water used (which could be raised from 25 c.c. to 300 c.c.) had any effect on rate of dispersion or the maximum dispersion obtained.

Results obtained with a drink mixer and simple shaking were of lower order and these methods were consequently not used except in the preliminary work. The most effective method, namely, shaking with sand, was examined in detail as it presented attractive possibilities. It requires practically no attention during the time the suspension is being shaken, and beyond the addition of the requisite amount of sand there is no preliminary treatment involved. Sand used for the purpose was of the coarse white variety having particles of about 1·5 mm. diameter. It was easily recovered after dispersion, by passing the suspension through a sieve of 1 mm. mesh, and used over and over again.

COMPARISON OF THE SAND METHOD WITH OTHER STANDARD METHODS

In view of the importance of these results in evolving, for practical use, a purely mechanical method of dispersion, and in view of the fact that the chemical methods are almost universally used in soil laboratories, it became imperative that the sand method should be compared with the chemical methods of dispersion. For this purpose 157 soils were used. These soils had been collected from different parts of India and represented practically all types. Also 59 H-soils were compared by the two methods. The results are given in Tables IV and V. The results for convenience of space are tabulated as difference between the two methods against the number of soils showing difference of that order. A plus sign indicates a higher value than the chemical method and the negative value a lower result.

TABLE IV

Comparison of clay contents obtained by dispersing natural soils with the proposed sand method and the chemical method

Difference between the clay per cent by the two methods	Number of soils showing difference of this order	
	+	—
0·0 to 1·0 . . .	33	18
1·1 to 2·0 . . .	13	14
2·1 to 3·0 . . .	19	10
3·1 to 4·0 . . .	13	9
4·1 to 5·0 . . .	10	7
5·1 to 6·0 . . .	1	*Nil*
6·1 to 7·0 . . .	2	1
7·1 to 8·0 . . .	*Nil*	*Nil*
8·1 to 9·0 . . .	*Nil*	*Nil*
9·1 to 10·0 . . .	*Nil*	*Nil*
10·1 to 15·0 . . .	3	*Nil*
15·1 to 20·0 . . .	3	*Nil*
20·1 to 25·0 . . .	1	*Nil*

For hydrogen soils the chemical method used was the addition of sufficient NaOH to bring the *p*H of the suspension to 10·8 and for natural soils Na_2CO_3-NaOH [Puri, 1936] method of dispersion was employed. The *p*H in this case was also brought to 10·8. The latter method may be regarded as the least drastic of all the chemical methods and therefore most appropriate for comparison with a purely mechanical method. The results revealed the following facts :

TABLE V

Comparison of clay contents obtained by dispersing H-soils with the proposed sand method and the chemical method

Difference between the clay per cent by the two methods	Number of soils showing difference of this order	
	+	—
0·0 to 1·0	2	4
1·1 to 2·0	2	5
2·1 to 3·0	4	1
3·1 to 4·0	*Nil*	2
4·1 to 5·0	2	3
5·1 to 6·0	3	2
6·1 to 7·0	5	1
7·1 to 8·0	3	*Nil*
8·1 to 9·0	5	*Nil*
9·1 to 10·0	4	1
10·1 to 15·0	4	4
15·1 to 20·0	*Nil*	*Nil*
20·1 to 25·0	1	1

1. The majority of natural soils (150) gave maximum dispersion with the sand method and the results agreed with the Na_2CO_3 method.

2. Some natural soils (7 out of 157) gave higher values with the sand method as compared to the Na_2CO_3 method.

All these seven soils, though from vastly different localities, belonged to one type, namely shales. The low values for these soils in the chemical method were due to the failure of the Na_2CO_3 method to bring about complete dispersion. When these soils were acid treated and then shaken with NaOH at pH 10·8 they dispersed completely and the values agreed with the sand method.

3. Only one natural soil gave a higher value by 7·6 per cent with the Na_2CO_3 method.

4. Six natural soils showed flocculation when the volume was made up after shaking with sand. When the soil had settled down and the clear supernatent liquid was poured off and replaced by fresh distilled water the suspension was stabilized. The flocculation in these soils was due to salts and when these were removed by a preliminary leaching with water, the dispersion was complete with sand.

5. Two natural soils persisted in being flocculated after dispersion with sand. No amount of preliminary leaching with water improved matters though a small amount of alkali stabilized the suspension and the yield of clay was maximum. These soils had low pH value and contained only Ca as the exchangeable base. On removing the exchangeable Ca by acid treatment the soil could be dispersed completely by the sand method. The dispersion was even slightly enhanced by the addition of $Ca(OH)_2$ but when the amount of $Ca(OH)_2$ was increased to the quantity originally present in the soil flocculation took place. It appears therefore that these soils contain exchangeable Ca just about the quantity required for flocculation which has either to be removed or rendered inactive by the addition of Na_2CO_3.

6. The agreement between the chemical and mechanical methods was not so close in the case of H-soils (Tabel V) as in the case of natural soils. This is evidently due to the fact that an acid treated soil has got very unfavourable pH value for the stabilization of the soil colloids and the difference between the reaction of the alkali treated and untreated soil is very great.

The results on the whole would leave no doubt that the sand method is an effective means of dispersing natural soils. A number of natural soils dispersed by Na_2CO_3 method and the sand method were subjected to complete mechanical analysis and the summation curves obtained by the two methods were found to be almost identical. There is thus no break down of the coarser fractions into particles that did not originally exist in the soil. The remarkable agreement between the mechanical and chemical methods of dispersion shows that neither the one nor the other is too drastic and that both give the size distribution of primary particles as they exist in soils.

As already mentioned chemical dispersion of a soil is not complete until a pH value of 10·8 is reached. At this pH the soil does not require any mechanical shaking. However, when chemical dispersion is aided by mechanical dispersion, the maximum dispersion is obtained at a lower pH value than otherwise. In other words the effect of chemical and mechanical dispersion becomes additive. This will be clear from Table VI in which the dispersion of a H-soil to which increasing amounts of alkalies have been added was completed with and without shaking with sand.

TABLE VI

Effect of combining chemical and mechanical methods of dispersion, P. C. 13 H-soil per cent clay ($<\cdot 002$ mm.)

Quantity of N/10 NaOH added to 10 gm. of soil in c.c.	No shaking with sand	Shaking with sand for 2 hours	Shaking with sand for 24 hours
0	1·2	21·0	54·2
3	4·0	29·5	55·5
5	6·6	33·1	55·5
10	13·2	34·0	55·5
15	18·8	37·5	55·8
20	21·4	40·0	55·0
30	28·5	44·7	55·4
40	37·5	49·5	55·5
50	49·5	53·0	56·0
60	55·0	55·2	55·5

The efficiency of the sand method for dispersing soils led to the speculation that this treatment may be too drastic for some soils so instead of breaking up the aggregates, some of the coarse primary particles as well might get broken up. Information on this point could be gathered by shaking a soil with sand for a much longer period than the prescribed 24 hours and to see if there is any tendency for the gradual increase of fine particles at the expense of the larger ones on continuous shaking. On shaking P.C. 13 soil for varying periods, up to a maximum of seven days, it was found that there was no increase in any fraction by shaking for longer periods and the percentages of various fractions obtained on seven days shaking were exactly the same as those obtained on 24 hours shaking The sand method therefore is not too drastic to break up primary particles.

The sand method, as pointed out before, presents the possibility of obtaining normally undispersed H-soils in a dispersed condition. The soil thus dispersed no longer remains so if it is dried. There is no known method by which a dispersed H-soil could be preserved in the dry state so that on coming in contact with water it might give a highly dispersed suspension. The fact that softer crumbs are produced when a soil wetted with alcohol is dried, led to the possibility of dispersing soil in alcohol in the first instance. The filtration of the alcohol dispersed soil is rapid and on drying it falls to a powder. It was found, however, that although the soil could be dispersed as in the case of water by shaking with alcohol, and there was also no difficulty in filtration but on drying it could not be redispersed in water. In order to test the possibility of this state of affairs being due to the traces of water present in alcohol attempts were made to exclude water completely during the final drying. The soil was dispersed in alcohol with sand, filtered and washed with alcohol, then with benzene and finally with ether. It was then dried in a current of dry air and kept in a desiccator until redispersed in water. Even with this treatment the soil could not be kept in a fully dispersed condition in the dry state though the dispersion was much greater than when water saturated dispersed soil was dried.

SUMMARY

Of the purely mechanical methods of dispersing soils, shaking for 24 hours with coarse sand is the most effective. The diameter of sand particles is one to two millimeters and the amount used is five times the weight of soil.

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A STUDY OF THE FERTILIZING VALUE OF THE SILTS CARRIED IN SUSPENSION BY THE RIVERS OF THE PUNJAB

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The investigation described in this paper had its origin in a discussion which took place at the Waterlogging Conference in Lahore in 1935. It was mentioned at that Conference that in order to prevent the further rise of bed levels of canals silt excluders were being fitted to the heads of some canals and distributories. Fears were expressed that the exclusion of this silt might reduce the supposed fertilizing properties of water. In this latter connection the view of the zamindars, who regard the silt carried by the river Ravi to be of greater fertilizing value than the silt in other rivers of the Punjab, was also put forth.

The utility of the excluded silt

The objections to the deposition of silt in the bed of a channel are the reduction in capacity of the canal, the raising of the full supply level and the consequent increase in seepage and the increased cost of maintenance of the banks which becomes necessary. Silt exclusion at the head of a canal is designed to deal only with that portion of the silt that is likely to form bed silt in some part of the system. It is, in fact, impossible to exclude much of the finer fractions of the silt as this tends to be evenly distributed throughout the depth of water in a channel and not concentrated in the bottom water as is the case with the coarser fractions.

The size of the particles forming bed silt in the main lines, branches and distributories of the Punjab canal system usually exceeds 0·05 mm. in diameter and is frequently situated in the range 0·05 mm. to 0·6 mm. in diameter. A survey of the watercourses to determine the size of the silt particles deposited in them had brought out, on the other hand, that almost all the particles less than 0·01 mm. in diameter remain in suspension and reach the fields. A comparison of the mechanical analysis of the sediment deposited in special tank from water of the river Nile and the mud from channel leading to sedimentation basins of Giza water service is given in Table I and confirms the observations made above. According to the International Classification of particle sizes the bed silt in the Punjab canals belongs to the fine and coarse sand fractions. While these fractions may be regarded as the frame work of the soil, little importance may be attached to them as sources of plant food. The exclusion from a canal system of material likely to form bed silt can have no effect on the fertilizing value of the silt laden water which reaches the fields. From the agricultural point of view, therefore, the examination of the fertilizing properties of silt particles below 0·01 mm. in diameter is more important.

Table I

Mechanical analyses of Nile silt

(By A. D. Hill, Director, Rothamsted Experimental Station)*

	Water from river, sedimented in special tank		Mud from channel leading to sedimentation basins of Giza Water Service	
	Dried at 100° per cent	Ignited per cent	Dried at 100° per cent	Ignited per cent
Retained by sieve above 0·2 mm.	..	..	..	..
1st sediment 0·2—0·04 mm.	0·60	0·58	10·25	10·05
2nd ,, 0·04—0·01 mm.	8·17	7·82	38·02	36·90
3rd ,, 0·01—0·004 mm.	17·53	16·62	10·33	9·54
4th ,, 0·004—0·002 mm.	10·40	9·15	7·08	5·85
Clay 0·002 mm.	50·24	42·92	26·64	22·33
Loss on solution	2·34	2·34	5·27	5·27
Moisture	8·58	8·58	4·64	4·64
Loss on ignition	..	10·27	..	7·06
	97·86	98·28	102·23	101·64

* Taken from the *Egyptian Irrigation* by Willcock & Craig

NATURE OF SILTS BROUGHT DOWN BY THE PUNJAB RIVERS

In the Punjab, the year can be divided into three periods with reference to both the type and quantity of silt in suspension in the river waters. The rivers commence to rise in March due to the melting of snow on the high hills. With this rise in the rivers, a grey silt is brought down to the plains. The production of this grey silt is most probably due to the physical weathering of the rock, and therefore, it consists of unchanged rock material in a fine state of sub-division. The grey silt is a potential source of fertilizing material which may be rendered available when the silt is subjected to chemical weathering in the plains.

When the rain falls in the hills during the monsoon period the character of the silt in the rivers changes. The run-off from the lower hills causes erosion of the soil and as a result the silt in the rivers has a red appearance. The silt in suspension in the rivers at this period, therefore, consists of a mixture of the grey silt derived from the high hills and soil eroded from the lower hills as the results of the rainfall. It might be expected that the silt in this period would contain more available fertilizing matter than in the pre-monsoon period, since a portion of the material has already been subjected to chemical weathering of the lower hills. On the other hand, since the silt is being transported in water, the available fertilizing constituents may go into solution and only the residue consisting of unweathered rock would reach the fields.

After the monsoon period the grey silt persists for a time but by the middle of November the water becomes clear and generally remains so until the following March. Freshets due to winter rains may occur during this period when a red silt derived from the soils of the lower hills comes in suspension.

EXPERIMENTAL

As there are three silt periods into which the year can be divided, it was decided to sample the silts in suspension in the rivers before, during and after the monsoons. Samples of silt in suspension were collected at the following sites on the various rivers over a period of two years 1935-36 and 1936-37:

(*i*) River Sutlej at Rupar
(*ii*) River Beas at Mandi
(*iii*) River Ravi at Madhopur
(*iv*) River Chenab at Marala
(*v*) River Jhelum at Rasul
(*vi*) River Indus at Ghazighat

The silts were analysed for the following:

(a) The mechanical analysis was done by the usual method.
(b) The total phosphate, potash and soda contents in the HCl extract were determined according to the method adopted by the Agricultural Education Association.
(c) The available phosphate content was done by the CO_2 extraction method [Puri and Asghar, 1936].
(d) The total nitrogen content was determined by the method proposed by Bal [1935].
(e) The calcium carbonate content was determined by the method proposed by Puri [1931].
(f) The *p*H values of the 1:5 suspensions were determined by the glass electrode [Hoon and Taylor 1931].
(g) The exchangeable bases were determined by the usual methods. The results of analyses are given in Tables II-V.

DISCUSSION OF RESULTS OF ANALYSES

(a) *Mechanical analysis*

As had been pointed out in section 2 above, the clay and fine silt only reach the fields during irrigation and therefore these fractions merit consideration. It will be seen from the results that the Indus and the Sutlej silts contain much higher proportions of silt and clay than those taken from the other rivers. The Jhelum during the monsoon period has a high content of silt and clay which indicates considerable soil erosion in its catchment area. The catchment areas of the Beas and Ravi are small, which probably accounts for the small amounts of clay and silt in the monsoon periods in these rivers. A further difference distinguishing these rivers, from the remainders, at the sampling sites is the velocity of the water. The Ravi and Beas at the sampling sites have boulder beds, the velocity of the water is high and consequently the amount of coarser material in suspension is high. The sampling sites on the Sutlej and Indus are well outside the catchment areas and the water velocities relatively low. The coarser material will have been deposited upstream of the sampling sites which would lead to an increase in the percentage of the finer fractions. The Chenab at Marala appears to have a low content of the finer fractions at all seasons. This may be due to the short tributaries from the Jammu hills which enter the river just above Marala and bring coarse material with them.

From the physical point of view, therefore, it would be expected that the plains irrigated from the Sutlej and Indus would tend to become heavier as regards soil type and that there would be

TABLE II

Analytical results of silt samples collected during the year 1935-36

Name of river	Name of site	Time of taking silt sample with reference to the rainy period	Per cent $CaCO_3$ content (on complete silt collected at site)	pH	Mechanical analysis Results expressed on air-dry basis)					†Clay as per cent fraction of the total 0·01 mm. particles in the silt sample	†† Per cent $CaCO_3$ content in the portion of silt reaching the field
					Sand >0·2	Fine sand from 0·2—0·02	Silt particles between 0·02 & 0·01	*Fine silt particles between 0·01 & 0·002	*Clay below 0·002 mm.		
1	2	3	4	5	6	7	8	9	10	11	12
Sutlej . .	Rupur . .	Before .	20·25	8·64	1·52	30·74	12·85	25·50	12·65	33·16	34·68
		During .	11·25	8·59	2·55	55·79	15·63	12·68	5·55	30·44	38·16
		After . .	6·50	8·40	21·68	43·25	11·23	10·65	3·20	23·10	31·93
Beas . .	Mandi (plain) .	Before .	1·50	8·35	1·72	65·98	12·15	10·88	4·80	30·61	8·73
		During .	1·50	8·42	7·42	69·92	12·23	7·18	2·80	28·06	13·07
		After . .	1·50	8·57	1·31	75·39	10·75	6·23	2·93	32·00	14·07
Ravi . .	Madhopur . .	Before .	Nil	7·83	...	...	...	...	1·20	...	...
		During .	0·50	7·57	27·07	52·36	10·88	4·85	1·88	27·94	6·92
		After . .	0·50	7·53	25·28	46·65	21·90	6·30	1·30	17·11	6·17
Chenab . .	Marala . .	Before .	2·0	9·12	21·11	64·86	6·25	1·10	1·45	56·88	43·95
		During .	2·38	8·22	0·65	50·94	16·45	17·63	9·90	35·96	7·96
		After . .	1·00	7·46	...	...	...	...	1·33	...	...
Jhelum . .	Rasul. . .	Before .	8·88	8·52	0·85	48·23	22·65	12·90	4·75	26·91	33·48
		During .	7·25	8·26	0·20	20·11	23·30	37·75	12·80	25·32	12·54
		After . .	8·50	8·41	6·0	46·20	21·68	13·65	4·05	22·88	32·44
Indus . .	Ghazighat . .	Before .	8·00	8·36	0·51	30·62	17·03	24·48	19·05	43·76	15·53
		During .	9·25	8·36	0·28	29·61	17·50	25·30	17·10	40·33	17·91
		After . .	10·50	8·50	...	...	...	...	28·28	...	...

* Columns 9 and 10: The fractions of the suspended silt that actually reaches the field.

† Column 11: $\frac{\text{Per cent clay (column 10)} \times 100}{\text{Per cent clay (column 10) + per cent fine silt (column 9)}}$

†† Column 12: The $CaCO_3$ is in a fine state and reaches the field along with particles of silt ranging from 0·01 mm. downwards. The per cent calcium carbonate in column (4) is determined on the complete silt. Its percentage in the fraction of the silt that reaches the field is calculated:—$\frac{\text{Per cent calcium carbonate (column 4)} \times 100}{\text{Per cent calcium carbonate (column 4) + per cent fine silt (column 9) + per cent clay (column 10)}}$

little change in the soils of the Ravi, Chenab and Jhelum areas. Deterioration of physical conditions may take place on the Sutlej and Indus but no material change would be expected on the areas served by the remaining rivers.

The conclusions regarding the Indus may be of considerable importance in the development of the Thal area. This area is situated between the Indus and Jhelum-Chenab rivers and is soon to be irrigated from the Indus by means of canals taking off at Kalabagh. The soils of the Thal consist of an unknown depth of loess resting on alluvium. This loess is easily erodable which may lead to high maintenance costs of the channels. It is very permeable, which means a low duty for the water and possibly a rapid rise in the water-table. The high content of the finer fractions in the Indus silt may lead to the formation of non-erodable berms in the canals as it will impart cohesion to the loess. It will also tend to increase the water retaining power of the soils and should result in time in an increase in the duty of the water.

(b) *Calcium carbonate content of silts*

It will be noticed that the calcium carbonate content of silts varies considerably from river to river. The highest quantities are present in the river Sutlej silts. A comparison of the figures for the pre-monsoon and monsoon periods clearly shows that the calcium carbonate is derived from the area in the snow-covered higher hills since the percentage falls with the addition of silt derived from the lower hills during the monsoon.

The silts of the Jhelum and Indus also have a high content of calcium carbonate. There is little difference in the percentages for the pre-monsoon and monsoon periods. This is probably

Table III

Analytical results of silt samples collected during 1935-36

Name of river	Name of site	Time of taking silt sample with reference to the rainy period	Analysis of the HCl extract		Results expressed in mgm. per 100 gm. of silts.			Exchangeable base content (Results expressed in mill-equivalents)			
			Per cent K_2O	Per cent Na_2O	Total P_2O_5 (in HCl extract)	Available P_2O_5	Nitrogen	Ca	Mg	K	Na
1	2	3	4	5	6	7	8	9	10	11	12
Sutlej . .	Ruper . .	Before .	0·70	0·09	95·73	1·20	6·00	28·50	1·60	0·38	0·22
		During .	0·61	0·08	109·10	1·28	8·40	17·40	2·30	0·37	0·52
		After . .	0·60	0·12	118·55	...	12·0	11·40	1·40	0·29	0·41
Beas . .	Mandi (plain) .	Before .	0·63	0·06	89·5	...	...	8·70	0·65	0·55	0·15
		During .	0·64	0·05	157·00	...	...	10·10	0·60	0·55	0·10
		After . .	0·51	0·05	181·85	...	...	8·70	0·63	0·39	0·21
Ravi . .	Madhopur . .	Before .	0·57	0·10	134·00	0·93	6·0	3·90	2·10	0·44	0·36
		During .	0·38	0·04	152·50	1·10	8·40	5·80	1·70	0·00	...
		After . .	0·60	0·06	94·55	0·90	8·40	4·20	1·10	0·14	0·26
Chenab . .	Marala . .	Before .	0·55	0·08	130·9	0·95	9·80	6·90	1·60	0·32	0·68
		During .	0·52	0·06	109·1	1·18	12·60	16·90	2·10	0·33	0·37
		After .	0·46	0·10	105·9	...	6·30	5·10	1·10	0·18	0·62
Jhelum . .	Rasul . .	Before .	0·55	0·13	140·10	1·50	14·0	14·70	2·80	0·76	0·04
		During .	0·98	0·12	146·10	1·88	24·50	17·70	1·50	0·99	0·11
		After . .	0·58	0·13	140·70	...	...	14·10	1·80	0·80	0·30
Indus . . .	Ghazighat . .	Before .	1·11	0·20	151·80	0·50	11·20	16·20	2·70	0·48	0·32
		During .	0·84	0·18	117·40	0·93	12·60	20·30	2·10	0·53	0·27
		After . .	1·33	0·18	95·70	0·75	21·00	19·20	2·20	0·52	0·18

Table IV

*Analytical results of silt samples collected during the year 1936-37**

Name of river	Name of site	Time of taking silt sample with reference to the rainy period	Per cent $CaCO_3$ content	pH	Mechanical analysis (Results expressed on air-dry basis)					clay as per cent fraction of the total 0·01 mm. particles in the silt sample	Per cent Ca Co_3 content in the portion of silt reaching the field
					Sand >0·20	Fine sand 0·2 to 0·02	Silt particles between 0·02 & 0·01	Fine silt particles between 0·01 & 0·002	Clay 0·00 2* mm.		
1	2	3	4	5	6	7	8	9	10	11	12
Sutlej . .	Rupar . .	Before .	10·00	7·68	1·44	42·01	14·18	22·93	7·00	23·38	25·04
		During .	5·50	8·24	2·78	43·20	12·50	22·59	9·40	29·05	14·83
		After . .	5·25	8·20	3·19	10·61	6·78	40·45	31·60	43·86	6·79
Ravi . .	Madhopur . .	Before .	0·75	7·70	20·29	40·56	14·25	17·90	2·70	13·11	3·51
		During .	0·50	7·87	4·19	49·14	20·16	18·98	2·98	13·57	2·23
		After . .	1·00	8·40	37·94	29·37	13·35	11·45	3·45	23·16	6·29
Chenab . .	Marala . .	Before .	3·25	7·90	10·36	52·03	17·40	18·00	2·90	13·88	13·46
		During .	3·00	8·18	0·73	67·19	14·23	9·05	3·05	25·21	19·87
		After . .	2·50	7·80	0·96	18·71	14·73	39·10	19·40	33·16	4·09
Jhelum . .	Rasul . .	Before .	8·75	8·20	1·36	79·84	7·55	2·90	0·45	13·43	72·32
		During .	7·75	8·28	0·70	36·69	13·80	27·50	8·15	22·89	17·86
		After .	10·86	8·14	1·89	27·39	25·45	25·45	7·05	21·69	25·05

* For explanation of the various columns see bottom of Table II

TABLE V

Analytical results of silt samples collected during 1936-37

Name of river	Name of site	Time of taking silt sample with reference to the rainy period	Analysis of the HCl extract: Per cent K_2O	Per cent Na_2O	Results expressed in mg. per 100 gm. of silts: Total P_2O_5 (in HCl extract)	Available P_2O_5	Nitrogen	Exchangeable base content (Results expressed in milli-equivalents): Ca	Mg	K	Na
Sutlej . .	Rupar . .	Before .	0·80	0·11	128·86	3·66	46·20	14·70	1·40	0·35	0·10
		During .	0·91	0·10	163·28	3·82	21·70	9·30	1·40	0·47	0·06
		After . .	1·50	0·07	100·0	2·63	47·32	14·80	2·28	0·83	0·07
Ravi . .	Madhopur . .	Before .	0·31	0·08	140·96	1·83	30·80	3·00	1·20	0·24	0·16
		During .	0·70	0·02	174·80	1·98	43·12	5·40	1·05	0·28	0·37
		After . .	0·76	0·05	110·00	1·53	53·62	4·00	0·58	0·36	0·04
Chenab . .	Marala . .	Before .	0·71	0·08	180·54	3·28	40·32	5·40	0·09	0·09	0·21
		During .	0·43	0·05	169·00	2·64	17·98	7·80	1·30	0·38	0·10
		After . .	1·37	0·05	100·0	1·83	54·32	17·40	2·25	0·39	0·11
Jhelum . .	Rasul . .	Before .	0·42	0·11	146·08	0·64	26·60	7·40	0·80	0·25	...
		During .	0·69	0·47	189·50	2·84	30·80	15·20	1·55	0·41	0·07
		After . .	1·25	0·12	160·00	1·87	62·08	13·80	1·18	0·56	0·04

due to the fact that the monsoon does not affect the catchment areas of these rivers to the same extent as those of the other rivers of the Punjab.

Next in importance with reference to calcium carbonate content is the silt of the Chenab river. The quantities of calcium carbonate reaching the fields (it is presumed that all the calcium carbonate content is very finely divided and is carried to the fields along with the clay and fine silts fractions in suspensions vide column 12, Tables II & IV) in the areas served by the canals taking off from the Chenab, however, will be relatively small. Both the Beas and the Ravi rivers have a very low calcium carbonate content.

The zamindars in the Punjab regard the Ravi silt as having the greatest fertilizing value. It is curious that this silt contains the lowest percentage of calcium carbonate and therefore this opinion appears to conflict with the views generally held on the value of calcium carbonate. A possible explanation is that it has not more fertilizing value but that it causes less deterioration of the soil. The soils of the Punjab plains generally contain sodium salts, the chief of which is sodium sulphate. As the result of the presence of these salts the soil becomes alkaline under irrigation and in the final stages of deterioration contains sodium carbonate. It had been shown experimentally [Puri, Taylor and Asghar, 1937] that calcium carbonate reacts with the alkaline sodium clay of the Punjab soils and sodium carbonate is rapidly formed. A silt high in calcium carbonate may therefore lead to the deterioration of soils similar to those in the Punjab while a silt low in calcium carbonate will have no harmful effect. On this basis some respect must be paid to the opinions held by the local zamindars. It is curious that support is lent to the above by the large areas of alkaline lands which occur in the Sutlej, Jhelum and Indus valleys and their absence in the areas served by the Upper Bari Doab Canal which takes off from the Ravi.

(c) The chemical analysis of the silts show very small quantities of nitrogen, phosphates and potash. It is doubtful whether after their transport with water for considerable distances any of these constituents would be available for the plant until they have been subjected to weathering after deposition.

No field experiments have been carried out to determine the fertilizing value of the silts. It is, however, a world-wide belief that silts have a definite fertilizing value. Analysis of silts in various parts of the world do not support this. It seems probable that the origin of the ideas regarding the fertilizing properties of the silt is bound up with water supply. In all countries where irrigation is practised water is the principal factor limiting crop yields. If a large deposit of silt is obtained it means that a big depth of water has been present and therefore that the reserve supplies of water in the soil after the deposition of the silt are greater in areas of high silt deposits than in areas of low silt deposit. This is the case in the basin irrigation practised in Upper Egypt. No

attempt seems to have been made to separate the effects of the silt and water factors.

SUMMARY

The chemical analysis of silts carried in suspension by the various rivers of the Punjab has been discussed in order to throw some light on their fertilizing properties.

It is shown that the silts contain very small quantities of nitrogen, phosphates, and potassium and cannot thus be regarded as direct fertilizers.

Differences between the silts of the various rivers have been brought out from a consideration of firstly the percentage fractions of the silts that are likely to reach the fields and secondly their calcium carbonate contents. It is shown that from the physical point of view the plains irrigated from the Sutlej and Indus would tend to become heavier as regards soil type and there would be little change in the soils of the Ravi, Chenab and Jhelum areas. Deterioration of physical conditions may take place on the Sutlej and Indus but no material change would be expected on the areas served by the remaining rivers.

Silts high in calcium carbonate may lead to deterioration of soils while those low in calcium carbonate will have no harmful effects.

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STUDIES ON BASE EXCHANGE

I. COMPARISON OF BASE EXCHANGE CAPACITIES AND DEGREE OF SATURATION OF SOME INDIAN SOILS OBTAINED BY DIFFERENT METHODS*

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In assessing the fertility and other properties of a soil, its base exchange capacity (b. e. c.) and content and nature of exchangeable bases are of importance. The methods in vogue, however, give different estimates of the same quantity and this lack of uniformity becomes more prominent when the exchangeable cation is partly or wholly hydrogen. The need of one method for each tpye of measurement which can be used for a wide variety of soils is obvious and has been emphasized by many [Russell, 1938]. Although this ideal may be difficult of accomplishment in view of differences in soils, an agreement as to which method is most suitable for a particular group of Indian soils is most desirable.

2. A comparative study has been made of the following methods :

Base exchange capacity (*T*)

(1) Parker's barium acetate-ammonium chloride method [Parker, 1929].

In addition to the estimation of Ba^{++} adsorbed from a neutral normal barium acetate solution, estimation was made of the NH_4^+ adsorbed from normal NH_4Cl solution used to displace the adsorbed Ba^{++}.

(2) Schollenberger and Dreibelbis' method [1930].

NH_4^+ adsorbed from a neutral normal ammonium acetate solution was estimated.

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Total exchangeable bases (S)

(3) R. Williams' method [1929].

S was also obtained by summing up the individual exchangeable bases separately estimated.

Individual exchangeable bases

(4) Hissink's method [1923].

(5) Hissink-Tiulin method [Tiulin, 1927].

These two methods were employed for estimating exchangeable Ca and Mg. Exchangeable Na K and also Mg and Ca of non-calcareous soils were estimated in the ammonium-acetate extract of method (2).

Exchangeable hydrogen

(6) Hardy and Lewis' method [1929].

(7) Titration with baryta in presence of N-$BaCl_2$. The amount of baryta required to attain *p*H 7·0 was estimated from the titration curve.

3. The soils which have been used for this comparison are enumerated in Table I.

4. The data are summarized in Table II.

Base exchange capacity. Methods 1 and 2 show good agreement both in the case of soils (Table II) and clays (Table III) although different cation effects are involved. The reaction between a salt and the soil absorption complex depends, besides other factors, on the *p*H of the equilibrium solution and the cation effects [Mitra, 1936; Mukherjee, Mitra and Mukherjee, 1937; Mitra, 1940; Mitra, Mukherjee and Bagchi, 1940; Mukherjee and Mitra, 1942]. At the high concentration (normal) of the salts used in methods 1 and 2, the high *p*H of the solution and the high degree of buffering offered by the acetates, the differences in the nature of the cation (i.e. the cation effect) becomes negligible. These different factors have been considered in greater detail in Part II of the paper.

TABLE I

Lab. No.	*Description*	*Calcium carbonate* (per cent)	*pH*
23	Ganges silt (Rajshahi Farm, Bengal)	3·8	6·2
46	Padegaon 'B' type, non-lateritic (0-12 in.), Nira, Poona	5·7	8·6
47	Padegaon 'D' type, non-lateritic (0-12 in.), Nira, Poona	6·1	8·5
53	Highland acid soil (0-6 in.) Latekujan experimental station, Assam	nil	5·3
55	Highland acid soil (0-6 in.), Oating, Assam	nil	5·0
10	Suri Farm soil, Bengal (0-6 in.)	nil	5·7
14	Burdwan Farm soil, Bengal (0-6 in.)	nil	5·8
20	Kalyanpur Farm soil, Cawnpur (0-6 in.)	0·54	7·3
25A	Black cotton soil from Satara, Bombay (0-6 in.)	2·6	8·5

TABLE II

Lab. No.	Soil	Base exchange capacity (T)			Total exchangeable bases		V = 100X S/T	*p*H (glass electrode)	Carbonate content (m.e.)	Exchangeable hydrogen		
		Schollenberger's method	Parker's									
			Ba^{++} adsorbed	NH_4^+ adsorbed	R. Williams' method	S = Ca + Mg + K + Na				Hardy and Lewis method	Titration with $Ba(OH)_2$ in presence of N-$BaCl_2$	T—S (calculated)
10	Suri	5·6	5·8	5·3	n. d.	5·0**	89·0	5·7	nil	0·3	0·6	0·6
14	Burdwan	6·3	6·5	6·9	4·3	4·1**	63·8	5·8	nil	0·2	0·8	2·4
16	Krishnagar	14·1	13·2	13·8	7·4	6·9	53·4	5·1	nil	1·8	2·2	6·2
20	Kalyanpur	11·9	11·6	11·8	13·9	13·7**	100·0	7·3	18·0	..	..	..
23	Rajshahi Ganges silt	14·6	15·3	15·1	..	14·5	96·7	8·7	126·7	..	..	..
25	Black cotton (Satara)	60·4	58·9	54·4	57·7	54·8**	96·0	8·3	86·3	..	..	..
46	Padegaon soil 'B' type	49·5	51·4	n. d.	..	47·0*	93·1	8·2	190·0	..	..	..
47	Padegaon soil 'D' type	64·4	65·3	64·7	..	63·8*	98·3	8·1	204·3	..	..	..
53	Acid soil (Latekujan)	8·1	8·3	8·0	3·6	3·7	45·0	5·4	nil	4·0	3·9	4·5
55	Acid soil (Oating)	7·5	8·0	8·1	2·6	2·6	33·0	5·3	nil	3·9	4·8	5·3

* Excluding K ** Excluding Na

Total exchangeable bases. The total content of exchangeable bases (S) estimated by method 3 is in agreement with the sum of the individual exchangeable bases separately determined in the case of the two acid soils only. With the other three soils containing high percentages of $CaCO_3$, the S values determined by the method 3 were not satisfactorily reproducible. Similar observations have been made by R. Williams himself [1929] with highly calcareous soils.

Degree of saturation. V ($= \frac{S}{T} \times 100$) values calculated from the average T and S show that soil Nos. 20, 23, 25, 46 and 47 are almost base saturated, the major constituent of the exchangeable bases being calcium. The calcium saturation has been brought about by the free $CaCO_3$ present in these soils. The soil reaction is alkaline. The degree of saturation of the rest of the soils varies from 33 to 64 per cent. These latter soils do not contain free $CaCO_3$ and have acidic reaction.

pH values. The *p*H values of the aqueous suspension of the soils determined by the glass electrode are given in Table II. The *p*H of the base saturated soils varies from 7·3 to 8·3 and that of acid soils from 5·1 to 5·8.

TABLE III

Base binding capacities of H-clays by different methods

Lab. No.	H-clays prepared from soils	Base binding capacity of clay		
		Paker's		Schollen-berger
		NH_4 + adsorbed	Ba++ adsorbed	
10	Suri . . .	37·0*	37·0*	..
20	Kalyanpur . .	..	54·6*	..
23	Rajshahi Ganges silt	48·1	53·0	50·4
46	Padegaon soil 'B' type	..	89·8	86·0
47	Padegaon soil 'D' type	..	102·7	97·0
53	Latekujan soil .	42·0	40·6	40·5
55	Oating soil . .	28·0	28·5	26·5

* Organic matter was removed from them by treatment with H_2O_2

Exchangeable hydrogen. Any excess of T over S means that the soil absorbing complex has replaceable cations other than those determined, viz. Ca, Mg, K and Na. The difference between T and S is usually bridged over by assuming the presence of hydrogen alone in an exchangeable form. Exchangeable hydrogen directly determined by methods 6 and 7 shows that the observed values are lower than those calculated as T-S (Table II). The lower value indicates that all the exchangeable hydrogen ions are not probably brought into a state of neutralization reactivity under the conditions of experiment. The higher value of exchangeable hydrogen obtained by method 7 is due to the higher concentration of the Ba++ ion and its stronger adsorbability§. In the case of the other five soils the *p*H on the addition of either $BaCl_2$ or $CaCl_2$, although it diminishes, remains above 7·0.

5. The values for exchangeable Ca and Mg in non-calcareous soils (Table IV) determined by methods 4, 5 and 2 agree very closely. Exchangeable K and Na estimated by method 2 are present in minute quantities.

6. Of the exchangeable bases, calcium constitutes about 70 to 90 per cent of the base exchange capacity of the base saturated soils. It is about 20 to 50 per cent in the case of the acid soils. Magnesium constitutes about 5 to 30 per cent of the b. e. c. of the different types of soils used. Potassium and sodium contents are 0·5 to 9 per cent and 0·8 to 5 per cent, respectively. Exchangeable hydrogen constitutes about 10 to 50 per cent of the b. e. c. of the acid soils.

7. *Comparison of soils.* The Padegaon 'B' and 'D' types and black cotton soils have the highest T-value (50 to 65 m. e.) corresponding to their high clay contents. They are also base saturated containing free $CaCO_3$ and the contents of both exchangeable Ca and Mg are high. Soil Nos. 20 and 23 have comparatively low T-value and are almost completely saturated with Ca alone. The rest are acid soils which (excepting soil No. 16) have very low T-value.

SUMMARY AND CONCLUSIONS

A comparative study has been made of some outline methods of determining the base exchange capacity, exchangeable bases, etc. of Indian soils as also of hydrogen clays isolated from them. Several types of soils have been selected for this work and the results on ten soils and seven hydrogen clays have been recorded in this paper.

The values of base exchange capacities (T) of soils and clays given by Schollenberger's and Parker's methods are in good agreement with each other. Rice Williams' method of determining S-value is not suitable for soils which contain fairly large quantities of $CaCO_3$. For non-calcareous soils, the contents of exchangeable Ca and Mg obtained by both Schollenberger's and Hissink-Tiulin mehods are in fair agreement. In the case

§ The estimation of the exchangeable hydrogen of the soil and the factors determining it have been discussed in detail in Part II

TABLE IV

Individual exchangeable bases in m. e. per 100 gm. of soil

Lab. No.	Soil	Ca	Mg	K	Na
10	Suri	2·8 Hissink-Tiulin 2·8 Schollenberger	1·9 Schollenberger	0·3	n. d.
14	Burdwan	3·2 Hissink-Tiulin 3·3 Schollenberger	0·6 Schollenberger	0·3	n. d.
16	Krishnagar	5·6 Hissink-Tiulin 5·3 Schollenberger	0·6 Schollenberger	0·5	0·2
20	Kalyanpur	10·2 Hissink-Tiulin 10·0 Hissink	2·7 Schollenberger	0·8	n. d.
23	Rajshahi Ganges silt	11·7 Hissink 11·2 Hissink	2·1 Hissink	0·4	0·5
25	Black cotton (Satara)	40·2 Hissink-Tiulin	14·3 Hissink-Tiulin	0·3	n. d.
46	Padegaon 'B' type	36·8 Hissink-Tiulin	9·8 Hissink-Tiulin	n. d.	0·4
47	Padegaon 'D' type	47·9 Hissink-Tiulin 48·1 Hissink	14·9 Hissink-Tiulin	0·9	n. d.
53	Acid soil (Latekujan)	2·0 Hissink-Tiulin 2·0 Schollenberger	0·7 Hissink-Tiulin 0·7 Schollenberger	0·6	0·4
55	Acid soil (Oating)	1·7 Hissink-Tiulin 1·6 Schollenberger	Trace Hissink-Tiulin Trace Schollenberger	0·7	0·2

of calcareous soils, the exchangeable Ca and Mg have to be determined by the Hissink or Hissink-Tiulin methods. Exchangeable hydrogen of acid soils determined by either Hardy and Lewis' method or by titration with baryta in presence of N-$BaCl_2$ is much less than the difference T—S. The degree of saturation of the soils V ($= \frac{S}{T} \times 100$) calculated from the average values of S and T range from about 33 to 64 per cent in the case of soils which do not contain free $CaCO_3$ and have acidic reaction, to about 100 per cent in the case of soils containing free $CaCO_3$. Of the exchangeable bases calcium constitutes about 70 to 90 per cent of the b. e. c. of the base saturated soils and about 20 to 50 per cent in the case of acidic soils. Exchangeable K and Na are present in very small quantities and the content of Mg is only appreciable (about 30 per cent) in the case of black cotton type of soils. Exchangeable hydrogen consitutes about 10 to 50 per cent of the b. e. c. of the acid soils.

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A STATISTICAL STUDY OF FLOWER PRODUCTION IN COTTON

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(With four text-figures)

In the first paper of this series [Afzal and Iyer, 1934] the growth in height of the main axis of the cotton plant was studied statistically and it was shown that Blackman's [1919] law of compound interest held good so far as rate of growth in height of the cotton plant at Lyallpur was concerned. It was also emphasized that Maskell's [1930] idea of presenting the developmental data of cotton in a simple and easily comparable form should be followed up by research workers in different parts of the world so that 'it may be more easily possible to compare the curves from one place with the curves from another place, and relate the changes to changing intensity of environmental factors'. With this idea in view the daily rate of growth in height was studied and it was found that the equation $H = Ae^{bt}$ could be fitted to the experimental curves. This study has now been carried a step further and an attempt has been made to find out a mathematical expression for the flowering curves of cotton. Although the value of flowering records to the plant breeder and the agronomist has been criticized by one of us [Afzal, 1941], these records are useful to the plant physiologist who is trying to disentangle the various growth phases of the cotton plant and to study the effect of environment on these growth phases.

It must be emphasized here that the rate of flowering is, perhaps, more important to the plant physiologist than the rate of growth in height as flowering immediately precedes boll formation. Prescott [1922] was the first to study statistically the flowering of cotton in Egypt. He used equation (*ii*) for this purpose.

$$(i)\ \text{Log}_e \frac{ax}{a-x} = kat$$

$$(ii)\ \text{Log} \frac{x}{a-x} = K\,(t-t_1)$$

$$(iii)\ \frac{dx}{dt} = kx\,(a-x)$$

where a is the total number of flowers produced, x is the number of flowers produced up to time t, and K and k are two constants, where $K = ak$ Loge $= 0{\cdot}4343\ ak$, and t_1 is the time when $x = a/2$. We have employed equation (*ii*) and it has been shown that the values of K are higher in Lyallpur than in Egypt. This may be due either to the varieties under experiment or the environmental conditions obtaining during the years of experiment at the two places.

Bartel and Martin [1938] have also employed the same equation in fitting curves to the dry weight per stalk and the grain weight per head of two varieties of grain sorghum, Dwarf Hegari and Double Dwarf Yellow Milo, under normal and late planting. They have also investigated the effect of seed size on the rate of growth of two varieties of corn, four of sorghum and one of proso and in every case the same logistic equation was found to fit the curves. It thus appears that the compound interest law has a very wide application in plant physiology studies.

Material

Three varieties of Punjab-American cotton (*G. hirsutum* L.) namely, 4F, 289F and 289F/43 and one variety of Punjab *desi* cotton (*G. arboreum* var. *indica Forma bengalensis*, H. & G.) 39 Mollisoni, were used for this purpose. It will not be out of place here to mention a few salient features of these strains.

4F. This is the oldest commercial variety of Punjab-American cottons. It was released by the Punjab Department of Agriculture for general cultivation in 1914 and has since then been one of the most popular varieties. This cotton is medium in maturity, giving its first picking in the 4th week of October. The fibre is 7/8 in. and is capable of spinning on the average 24 highest standard warp counts. Flowering records are available for seven years.

289F. This variety was grown on a commercial scale for the first time in 1921 in the Lower Bari Doab Canal Colony and was very popular in some parts of it. The area under this cotton is now decreasing. This variety is later than 4F, giving its first picking in the second week of November. Its fibre length is $1\frac{1}{32}$ in. and has been adjudged as capable of spinning 44 highest standard warp counts. Flowering records are available for seven years.

289F/43. This is a very early maturing variety and was released for general cultivation in 1934. Due to its early maturing habit and drought resistance it has found great favour in the parts of Lower Bari Doab Canal Colony and south western

districts of the Punjab. Its fibre length is $1\frac{1}{32}$ in. and has been adjudged as capable of spinning 40 highest standard warp counts. Flowering records are available for three years.

39 Mollisoni. This is the most popular variety of Punjab *desi* cottons in the Central Canal Colony districts of the Punjab and occupies about 39 per cent of the total area under *desi* cotton in the province. The fibre length of this variety is 5/8 in. and is capable of spinning 9 highest standard warp counts. Flowering records of this cotton are available for five years.

The procedure for recording the daily production of flowers was the same as employed in Egypt. Before the commencement of flowering 200 A. P. (average plants, meaning plants of average size and normally spaced) were selected at random and the actual number of flowers which opened on these plants every day was recorded on special cards prepared for the purpose. The casualties during the course of the season were carefully noted and the average number of flowers produced per plant per day (P. P. p. d.) were worked out. These data along with the summation data were used in the statistical analysis.

One peculiarity of the Punjab-American cottons may here be noted. All flowers produced on these varieties up to or about the middle of August are shed due to the non-dehiscence of anthers [Trought, 1928]. Thus the 'effective' flowering in these varieties starts from the beginning of September. No non-dehiscence of anthers occurs in 39 Mollisoni and other indigenous cottons.

Method

(*a*) *Summation curves*. The flowering season was divided up into intervals of five days and the total number of flowers produced per plant up to each interval was plotted. The summation curves of all the varieties were of the characteristic S-shape. In order to see the goodness of fit of the calculated with the observed summation curves, the logistic equation $\text{Log}\ \frac{x}{a-x} = K\ (t-t_1)$ was transformed as $Y = A + Bt$ where $Y = \log \frac{x}{a-x}$, $A = -Kt_1$, $B = K$.

As all the summation curves were asymmetrical it was necessary to fit an equation of the general nature, such as $Y = A + Bt + Ct^2 + Dt^3$.

Since the independent variable occurred at equal intervals, the regression curves of the third degree were fitted to each variety for the different years by the method of orthogonal polynomials given by Fisher [1936]. The origin was taken on the date of first flowering, but in the actual calculations, the first observation was neglected as the number of flowers on the date of origin was extremely small.

The third degree curves were fitted to the data and the analysis of the sum of squares contributed by the linear, the quadratic and the cubic regressions was worked out and is given in Table I.

TABLE I

Analysis of sum of squares

1	2	3	4	5	6	7	8	9	10
Year	Total d.f.	Total S. S.	Linear component	Q. component	Cubic component	Residual	Per cent L. C. / Total	Per cent Q. C. / Total	Per cent C. C. / Total
289F.									
1926-27 . .	15	45·1771	44·1461**	0·8110**	0·0299	0·1901	97·72	1·80	0·07
1927-28 . .	21	65·9184	59·3262**	5·6471**	0·1524	0·7927	90·00	8·57	0·23
1928-29 . .	22	60·7235	57·7149**	1·3204**	0·6126**	1·0756	95·05	2·17	1·01
1929-30 . .	13	35·9565	35·3784**	0·0002	0·1745	0·4034	98·39	0·001	0·49
1930-31 . .	20	69·2945	56·4386**	11·4319**	0·2860	1·1380	81·45	16·50	0·41
1931-32 . .	19	40·6052	34·6213**	5·4794**	0·3061**	0·1984	85·26	13·49	0·75
1932-33 . .	11	31·4646	29·9939**	0·5521**	0·7793**	0·1393	95·33	1·75	2·48

TABLE I—*contd.*

1	2	3	4	5	6	7	8	9	10
Year	Total d.f.	Total S. S.	Linear component	Q. component	Cubic component	Residual	Per cent L. C. Total	Per cent Q. C. Total	Per cent C. C. Total
4F.									
1926-27	24	118·5894	115·4529**	0·0002	0·3579	2·7784	97·36	0·0002	0·30
1927-28	23	65·6088	55·4122**	5·1611**	4·5657**	0·4698	84·46	7·87	6·96
1928-29	22	63·2408	60·7436**	2·1158**	0·0088	0·3726	96·05	3·35	0·014
1929-30	14	46·1944	44·6832**	0·0314	0·4129	1·0669	96·73	0·07	0·89
1930-31	18	43·3527	32·2392**	9·1691**	1·8826**	0·0618	74·36	21·15	4·34
1931-32	20	37·3880	36·1486**	0·5053**	0·4413**	0·2928	96·69	1·35	1·18
1932-33	10	33·8449	33·3990**	0·1132	0·2517**	0·0810	98·68	0·33	0·74
289F/43.									
1930-31	17	47·8601	45·1559**	2·1244**	0·3711**	0·2087	94·35	4·44	0·78
1931-32	21	40·0819	35·1498**	2·3367**	2·1723**	0·4231	87·69	5·83	5·42
1932-33	16	64·6079	64·0812**	0·2286**	0·0619	0·2362	99·18	0·35	0·096
Mollisoni.									
1928-29†	11	16·4141	15·8559**	0·4956**	0·0426**	0·0200	96·60	3·02	0·26
1929-30	12	40·2026	39·5666**	0·1674**	0·4620**	0·0066	98·42	0·42	1·15
1930-31	16	48·8633	48·1078**	0·6353**	0·0191	0·1011	98·45	1·30	0·039
1931-32†	9	12·9864	12·8324**	0·1368**	0·0127**	0·0045	98·81	1·05	0·098
1932-33	14	48·7757	48·2423**	0·0009	0·0060	0·5265	98·91	0·002	0·012

† During these two years there were two flushes of flowers but only the first which was the main flush has been considered. But by leaving out the 2nd flush a further asymmetery was introduced in the summation curves.

It will be seen from Table I that the percentage of sum of squares contributed by the linear regression was overwhelmingly large and that the mean variance due to the linear regression was always highly significant, whereas that for quadratic and cubic was also significant in a large number of cases. This was because of the asymmetrical nature of the actual summation curves in comparison to the symmetrical curves obtained by the equation Log $\frac{x}{a-x} = K\ (t-t_1)$.

Since the method of orthogonal polynomials has the advantage of reducing the equation from any higher degree to the lower ones, the constants of the cubic, quadratic, as well as those of the linear ones could be easily obtained for all the varieties in the different years. The average polynomial curves for each variety were found to be significant up to the third degree and for the sake of brevity only the cubic equations are given in Table II.

The values of Y as calculated from the linear, quadratic and the cubic equations (Table II) as well as the observed values were plotted against the time interval and by way of illustration the graphs for 1930 are given in Fig. 1. It will be seen from Fig. 1 that the cubic equation gave the best fit in the case of all the three American varieties, while both the quadratic and the cubic equations gave a better fit than the linear equation in the case of Mollisoni. The trend was similar in other years also, which will be dealt with in detail later on.

After having calculated Y, the number of flowers x at any time t was calculated by the transformation needed in the equation $Y = \log \frac{x}{a-x}$.

TABLE II

Cubic equations

Variety		Season	Equation
289F	(*i*)	1926-27	$Y = -2\cdot223{,}965 + 0\cdot260{,}338t - 0\cdot002{,}721t^2 + 0\cdot000{,}574t^3$
	(*ii*)	1927-28	$Y = -3\cdot036{,}772 + 0\cdot070{,}324t - 0\cdot000{,}361t^2 + 0\cdot000{,}420t^3$
	(*iii*)	1928-29	$Y = -2\cdot739{,}243 - 0\cdot151{,}149t + 0\cdot031{,}447t^2 - 0\cdot000{,}714t^3$
	(*iv*)	1929-30	$Y = -3\cdot960{,}136 + 0\cdot702{,}187t - 0\cdot049{,}969t^2 + 0\cdot002{,}233t^3$
	(*v*)	1930-31	$Y = -2\cdot538{,}557 - 0\cdot024{,}527t + 0\cdot000{,}214t^2 + 0\cdot000{,}678t^3$
	(*vi*)	1931-32	$Y = -2\cdot373{,}837 + 0\cdot082{,}995t - 0\cdot008{,}573t^2 + 0\cdot000{,}833t^3$
	(*vii*)	1932-33	$Y = -4\cdot381{,}010 + 1\cdot587{,}700t - 0\cdot180{,}278t^2 + 0\cdot008{,}202t^3$
4F	(*i*)	1926-27	$Y = -4\cdot157{,}060 + 0\cdot130{,}067t + 0\cdot015{,}923t^2 - 0\cdot000{,}410t^3$
	(*ii*)	1927-28	$Y = -3\cdot441{,}440 + 0\cdot595{,}048t - 0\cdot052{,}526t^2 + 0\cdot001{,}690t^3$
	(*iii*)	1928-29	$Y = -2\cdot344{,}066 + 0\cdot089{,}859t + 0\cdot004{,}633t^2 + 0\cdot000{,}086t^3$
	(*iv*)	1929-30	$Y = -3\cdot875{,}283 + 0\cdot781{,}191t - 0\cdot061{,}682t^2 + 0\cdot002{,}685t^3$
	(*v*)	1930-31	$Y = -2\cdot274{,}375 + 0\cdot327{,}454t - 0\cdot048{,}282t^2 + 0\cdot002{,}476t$
	(*vi*)	1931-32	$Y = -2\cdot859{,}312 + 0\cdot362{,}501t - 0\cdot023{,}040t^2 + 0\cdot000{,}842t^3$
	(*vii*)	1932-33	$Y = -3\cdot793{,}054 + 1\cdot264{,}579t - 0\cdot126{,}378t^2 + 0\cdot006{,}383t^3$
289F/43'	(*i*)	1930-31	$Y = -2\cdot723{,}779 + 0\cdot329{,}255t - 0\cdot023{,}625t^2 + 0\cdot001{,}332t$
	(*ii*)	1931-32	$Y = -2\cdot526{,}275 + 0\cdot504{,}729t - 0\cdot045{,}603t^2 + 0\cdot001{,}585t^3$
	(*iii*)	1932-33	$Y = -4\cdot355{,}070 + 0\cdot627{,}268t - 0\cdot023{,}413t^2 + 0\cdot000{,}666t^3$
Mollisoni	(*i*)	1928-29	$Y = -2\cdot952{,}286 + 0\cdot785{,}741t - 0\cdot056{,}652t^2 + 0\cdot001{,}917t^3$
	(*ii*)	1929-30	$Y = -3\cdot278{,}704 + 0\cdot916{,}158t - 0\cdot090{,}333t^2 + 0\cdot004{,}737t^3$
	(*iii*)	1930-31	$Y = -2\cdot544{,}269 + 0\cdot254{,}428t - 0\cdot000{,}937t^2 + 0\cdot000{,}370t^3$
	(*iv*)	1931-32	$Y = -2\cdot907{,}296 + 0\cdot725{,}994t - 0\cdot049{,}607t^2 + 0\cdot002{,}031t^3$
	(*v*)	1932-33	$Y = -2\cdot586{,}976 + 0\cdot568{,}367t - 0\cdot023{,}865t^2 + 0\cdot001{,}014t^3$

The values of x as calculated from the values of Y, derived from the linear, quadratic and the cubic equations with the help of the above equation were plotted along with the observed values. The curves for 1930 only are given in Fig. 2. It will be seen that the observed and the calculated values of x have a similar trend and that the cubic regression usually gave a much closer fit than both the linear and the quadratic regressions.

(*b*) *Average polynomial curves.* After having fitted the regression equations for the individual years, it is now possible to calculate an average polynomial curve for each variety. Thus the variations due to environmental conditions from year to year will be eliminated and the normal average rate of flower production in each variety can be found out. It will also then be possible to compare the different varieties between themselves.

In order to find the trend of the average polynomial curve, the sum of squares for the average linear, quadratic and cubic regressions as well as those due to the heterogeneity of the seasonal curves from the average regressions were calculated. The following method was employed for this purpose.

If the polynomials for r seasons be represented as :

$$Y_1 = a_1 + b_1 x + c_1 x^2 + d_1 x^3 + \ldots\ldots\ldots + p_1 x^n$$
$$Y_2 = a_2 + b_2 x + c_2 x^2 + d_2 x^3 + \ldots\ldots\ldots + p_2 x^n$$
$$\text{———————————————}$$
$$\text{———————————————}$$
$$Y_r = a_r + b_r x + c_r x^2 + d_r x^3 + \ldots\ldots\ldots + p_r x^n$$

and the number of observations for the seasons be $N_1, N_2, N_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots N_r$, the above equations can be transformed as suggested by Tippett [1937] :

$$Y_1 = A_1 + B_1 T_1 + C_1 T_2 + D_1 T_3 + \ldots\ldots + P_1 T_n$$
$$Y_2 = A_2 + B_2 T_1 + C_2 T_2 + D_2 T_3 + \ldots\ldots + P_2 T_n$$
$$\text{———————————————}$$
$$\text{———————————————}$$
$$Y_r = A_r + B_r T_1 + C_r T_2 + D_r T_3 + \ldots\ldots + P_r T_n$$

The average polynomial of the nth degree would be given by :

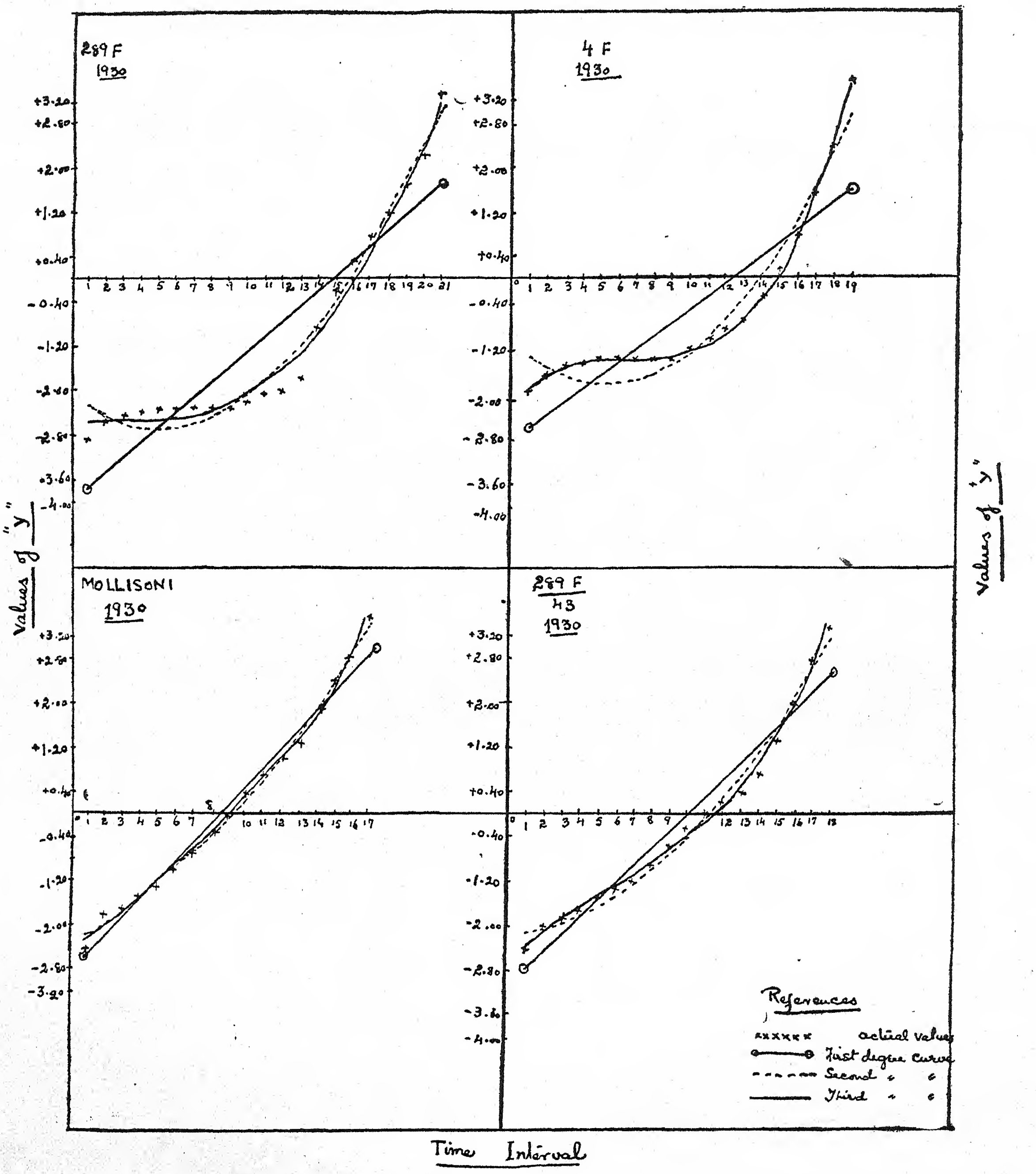

FIG. 1. Orthogonal polynomial curves and the actual values of 'y' for 1930

$$Y = A + BT_1 + CT_2 + DT_3 + \ldots\ldots\ldots\ldots + PT_n$$

where $A = \dfrac{\Sigma_1^r \, (\Sigma \, Y)}{\Sigma_1 N}$; $B = \dfrac{\Sigma_1 \quad (\Sigma \, yT_1)}{\Sigma_1^r \dfrac{N\,(N^2\text{-}1)}{(12)}}$

$$C = \frac{\Sigma_1^r \, (\Sigma \, y \quad T_2)}{\Sigma_1^r \dfrac{N(N^2 - 1)(N^2 - 4)}{180}}$$

and similarly the other coefficient can be calculated.

A test of significance for the heterogeneity of the regression curves can be made in a manner similar to that for the linear regression. For any individual curve, the sum of squares for any regresssion coefficient can be easily computed as indicated below :

$$\text{S. S. for linear regression (B)} = B^2 \left\{ \Sigma \frac{N(N^2-1)}{12} \right\}$$

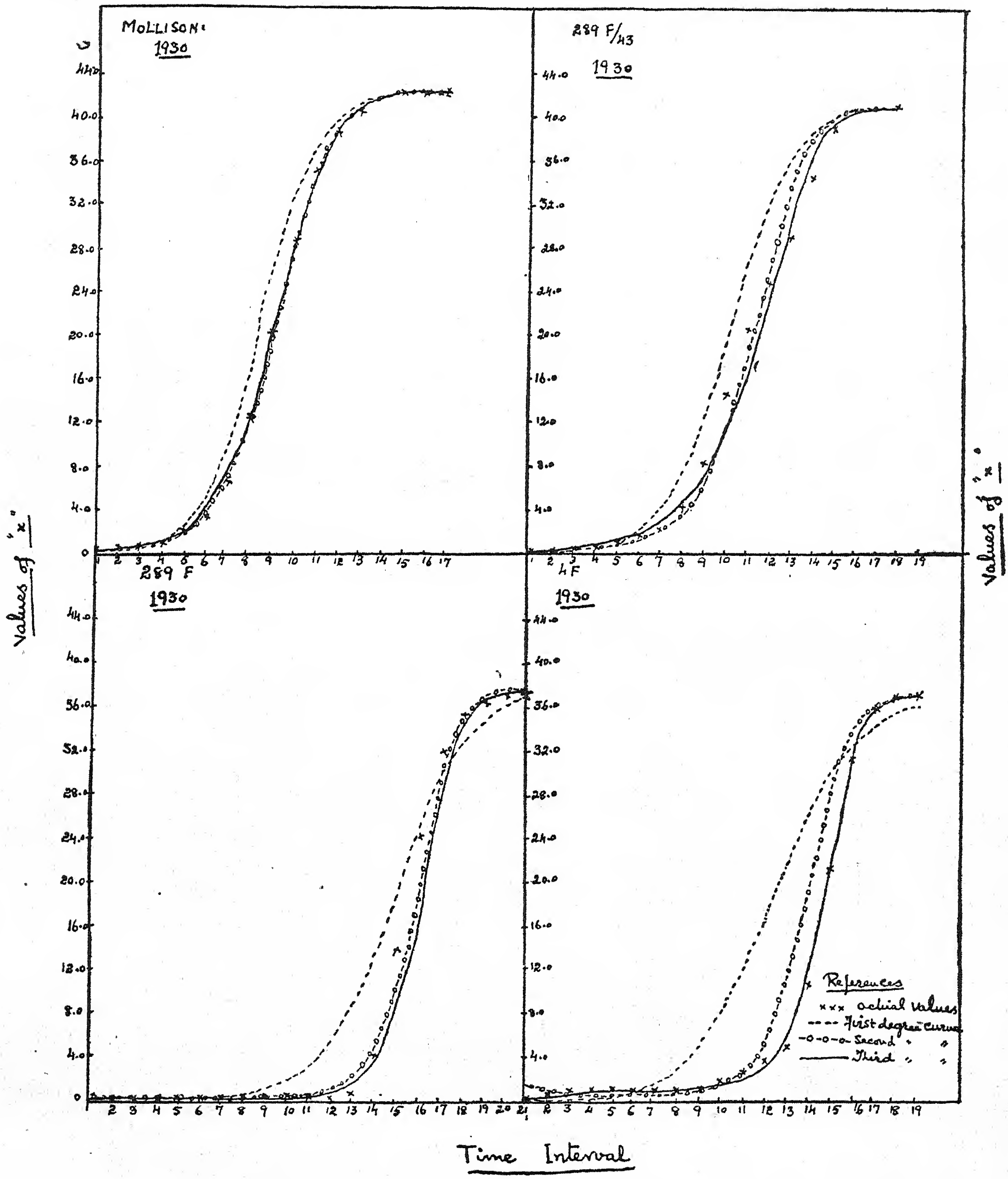

FIG. 2. Values of 'x' obtained from the polynomials and the actual data for 1930

S. S. for quadratic regression (C)

$$=C^2 \left\{ \Sigma \frac{N(N^2-1)\,(N^2-4)}{180} \right\}, \text{ etc.}$$

each corresponding to one degree of freedom. Thus for r seasons the total sum of squares for any regression coefficient will have r degrees of freedom out of which one will represent the sum of squares corresponding to the average curve and the remaining (r—1) represent the deviations from the average curve. These may be tested against the residual sum of squares obtained by adding the residuals for the individual years.

The so transformed average curve can be converted into a polynomial in t in the same manner as was done for the seasonal curves. One fact that needs illustration is that the value of N was taken as the average of $N_1, N_2 \ldots\ldots\ldots Nr$ and in case it did not come out to be a whole number, a suitable change was made in the number of observations*.

The sum of squares of the average regression curves and the deviations are given in Table III.

It will be seen from Table III that the linear, quadratic and the cubic regressions as well as the heterogeneity between these regressions was significant except the average quadratic regression in 39 Mollisoni and the heterogeneity in the cubic regression in the case of 289F and 289F/43. The significance of the deviations of the yearly curves from the average curve indicates that the seasonal factors affect the rate of flower production of cotton at Lyallpur in a very large measure.

Looking at the mean squares, it is found that the linear component in all cases was overwhelmingly large as compared to the quadratic and cubic components, but as the cubic component was also significant, it may, therefore, be deduced that the average polynomial curve of the third degree would represent the normal rate of flower production of cottons at Lyallpur. The sum of squares due to the deviations from the average regression curves was comparatively less in 39 Mollisoni than in the American varieties. The yearly as well as the average polynomial curves for all the varieties are given in Fig. 3. The curves for 39 Mollisoni again indicate a very close similarity.

The third degree equations for all the varieties are given below :

289F	$Y = -2\cdot521{,}570 + 0\cdot067{,}118t + 0\cdot006{,}383t^2 + 0\cdot000{,}271t^3$
4F	$Y = -2\cdot778{,}472 + 0\cdot389{,}980t - 0\cdot027{,}300t^2 + 0\cdot001{,}174t^3$
289F/43	$Y = -2\cdot977{,}650 + 0\cdot470{,}095t - 0\cdot035{,}222t^2 + 0\cdot001{,}435t^3$
39 Mollisoni	$Y = -2\cdot631{,}531 + 0\cdot533{,}466t - 0\cdot027{,}951t^2 + 0\cdot001{,}409t^3$

* The average polynomial can also be converted by employing the following formulae :

$$T_2 = (t-\bar{t})^2 - \mu_2\,;\quad T_3 = (t-\bar{t})^3 - \frac{\mu_4}{\mu_2}(t-\bar{t})$$

$$\text{where } \mu_2 = \frac{\Sigma_1[\Sigma(t-\bar{t})^2]}{\Sigma N} \text{ and } \frac{\mu_4}{\mu_2} = \frac{[\Sigma^r{}_1\,\Sigma\,(t-\bar{t})^4]}{\Sigma_1\,[\Sigma\,(t-\bar{t})_2]}$$

where μ_2 and μ_4 are the second and the fourth moments of t.

The equation for 289F/43 was checked by this method and it worked out as follows :

$Y = -2\cdot969{,}744 + 0\cdot471{,}352t - 0\cdot035{,}751t^2 + 0\cdot001{,}435t^3$ which agrees very well with the equation obtained by the previous method.

RELATIVE RATE OF FLOWER PRODUCTION

The relative rate of flower production can be ascertained by differentiating the equation $Y = A + Bt + Ct^2 + Dt^3$ with respect to the independent variable t.

$$\frac{dy}{dt} = B + 2CT + 3Dt^2\,;\ \text{but}\ Y = \log\frac{x}{a-x}$$

$$\text{Therefore } \frac{dy}{dt} = \frac{dx}{dt}\cdot\frac{a\log_{10}^{e}}{x(a-x)} = (B+2Ct+3Dt^2)$$

$$\text{or } \frac{dx}{dt} = \frac{(B+2Ct+3Dt^2)}{a\log}\ .\ x(a-x)$$

Thus the deduced equation is comparable to equation (*iii*). From the analogy with the compound interest law, k in equation (*iii*) may be looked upon as the true or absolute rate of flower production corresponding to the rate of interest. The actual rate at any time depends upon k as well as the number of flowers already produced up to any particular time. The constant $K = a\,k\log_{10^e}$, which contains the element a, probably characteristic of a variety may then be called the absolute rate of flower production for the variety.

On comparing the new equations for the rate of flower production with equation (*iii*), we find K comparable to $\dfrac{(B+2Ct+3Dt^2)}{a\log_{10^e}}$ and so K can easily be compared with $(B+2Ct+3Dt^2)$. Here it may be mentioned that Prescott [1922] found that the relative rate of flower production, K, was constant for a variety over a season, but we have found that the relative rate of flower production was a function of time, witness the significant deviations from the linear regression. The equations for the relative rate of flower production from the average curves are given below :

289F	$\frac{dy}{dt} = 0\cdot067{,}118 + 0\cdot012{,}676t + 0\cdot000{,}813t^2$
4F	$\frac{dy}{dt} = 0\cdot389{,}980 - 0\cdot054{,}600t + 0\cdot003{,}522t^2$
289F/43	$\frac{dy}{dt} = 0\cdot470{,}095 - 0\cdot070{,}444t + 0\cdot004{,}305t^2$
39 Mollisoni	$\frac{dy}{dt} = 0\cdot533{,}466 - 0\cdot055{,}902t + 0\cdot004{,}227t^2$

The average relative rates of flower production over the whole season calculated from the yearly equations of all the varieties are given in Table IV.

It will be seen from Table IV that the relative rate of flower production was higher in the case of indigenous variety (39 Mollisoni) as compared to the American varieties, which did not vary very much amongst themselves.

TABLE III

Sum of squares of the average regressions

Due to	4F			289F			289/F43			39 Mollisoni		
	D.F.	S. S.	M. S.	D.F.	S. S.	M. S.	D.F.	S. S.	M. S.	D.F.	S. S.	M. S.
Linear regression	1	306·492,685	306·492,685**	1	287·144,851	287·144,851**	1	132·860,100	132·860,100**	1	142·961,522	142·961,522**
Quadratic regression . .	1	8·644,306	8·644,306**	1	21·604,339	21·604,339**	1	2·844,704	2·844,7044**	1	0·032,522	0·032,522
Cubic regression . . .	1	5·808,602	5·808,602**	1	1·969,913	1·969,913**	1	2·501,120	2·501,120**	1	0·297,346	0·297,346**
Deviations from average linear regression	6	20·306,501	3·384,416**	6	13·722,504	2·287,084**	2	11·526,764	5·763,382**	4	2·834,949	0·708,737**
Deviations from average quadratic regression	6	9·254,374	1·542,396**	6	3·494,590	0·582,432**	2	1·845,057	0·922,529**	4	1·045,407	0·261,350**
Deviations from average cubic regression	6	1·855,579	0·309,263**	6	0·436,628	0·072,771	2	0·104,139	0·052,069	4	0·238,668	0·059,667**
Residual	105	3·948,731	0·037,607	98	3·787,358	0·038,647	45	0·868,024	0·019,289	45	0·657,372	0·014,608
Total .	126	356·310,777	...	119	332·160,183	...	54	152·549,908	...	60	148·067,779	...

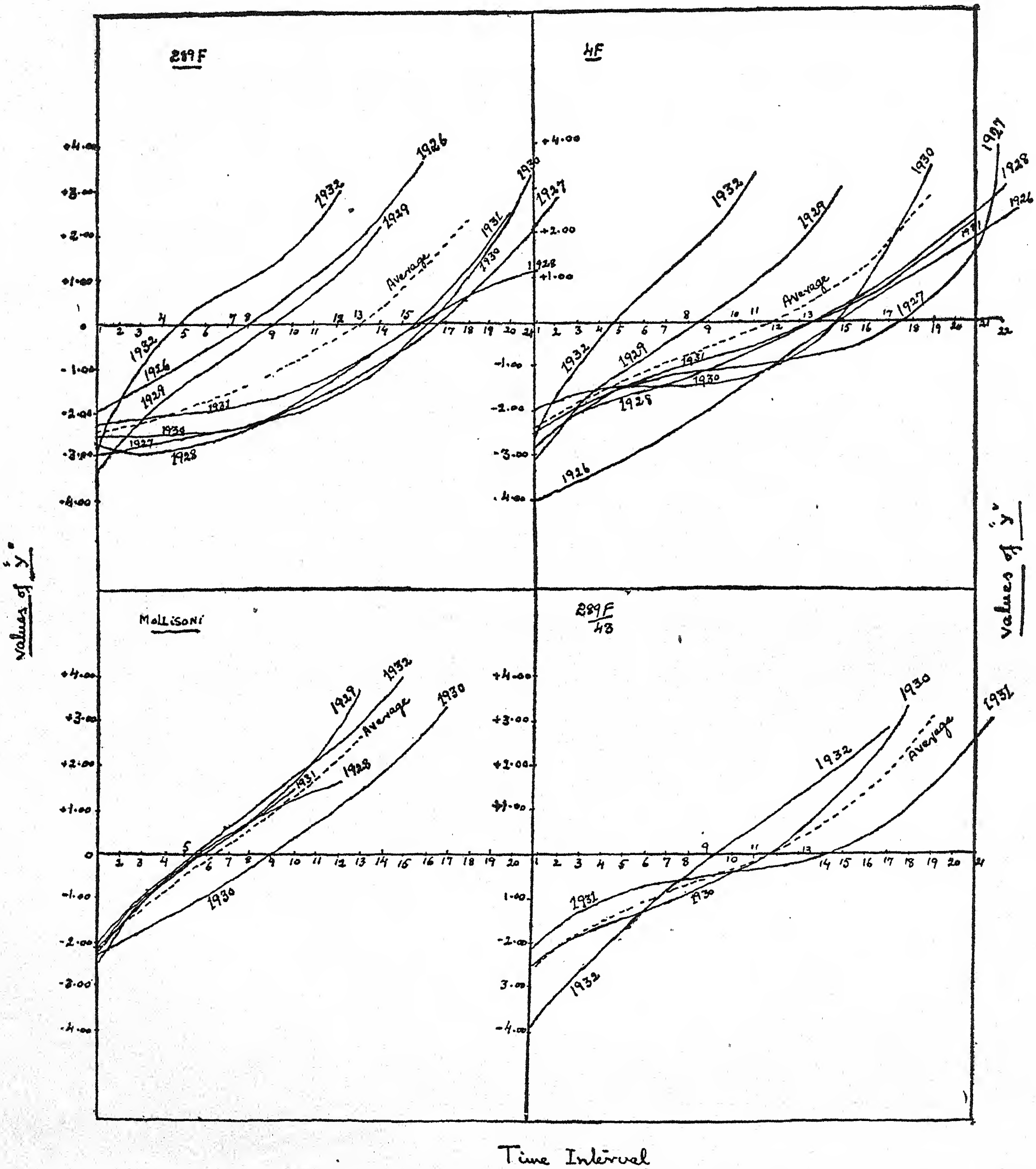

Fig. 3. Deviations of yearly polynomials from the average

A comparison of the indigenous variety, 39 Mollisoni, with the three acclimatized American varieties reveals that the fluctuations in flower production from year to year are far less in the indigenous variety as compared to the American strains. This means that 39 Mollisoni is more adapted to the local conditions than the American varieties.

Growth in height and flower production

It will now be interesting to compare the rate of growth in height with the rate of flower production. It has already been shown [Afzal and Iyer, 1934] that Mollisoni had a higher rate of growth in height and now we find the rate of flower production in this cotton is also higher than the American varieties. The correlation between the rate

TABLE IV

Average relative rate of flower production

Variety	1926-27	1927-28	1928-29	1929-30	1930-31	1931-32	1932-33
289F . . .	0·0721	0·0518	0·0478	0·0789	0·0541	0·0456	0·0916
4F . . .	0·0596	0·0439	0·0490	0·0799	0·0476	0·0433	0·1102
289F/43 . .	..	..	..	..	0·0611	0·0399	0·0793
Mollisoni . .	..	..	0·0666	0·0933	0·0687	0·0789	0·0830

of growth in height and flower production between varieties ($n = 2$) was $r = 0 \cdot 9745$ which was significant at 5 per cent level. This indicates that if in any particular variety X under experiment in any particular year, the rate of growth in height was higher than in any other variety Y in the same year, the rate of flower production will also be higher in X as compared to Y.

It will be well to speculate on this phenomenon in terms of genes. It can be argued that the genes responsible for the vegetative growth as well as those for the flower production attended by their plus and minus modifiers are not assorted independently of one another but are closely linked and can therefore be considered to be located on the same chromosome in close proximity to one another.

A comparison of the rate of growth in height and flower production for any one variety in different seasons, however, showed that the high rate of growth in height depressed the rate of flower production. The values of the average efficiency indices (b) for height and the relative rate of flower production (K) are plotted for each variety in Fig. 4.

It will be seen from Fig. 4 that the peaks for the two rates always stand face to face and therefore it can be said that in any one year when the rate of growth in height was higher, the rate of flower production was expected to be low. The correlations worked out between these two coefficients within the American varieties and for Mollisoni were :

$$r_{Am} = -0 \cdot 3011 \qquad n = 13$$
$$r_{M} = -0 \cdot 6418 \qquad n = 3$$

Although both these correlations were non-significant, the negative trend is patent and the two rates of growth herein dealt with were probably opposed to one another. The high rate of vegetative growth meant a low rate of reproductive growth. This phenomenon is within the experience of the cultivator in the Punjab and in any one year when the cotton crop makes luxuriant vegetative growth, the yield is decreased.

Since it has already been shown that the genes responsible for vegetative growth and flower production lie close to one another on the same chromosome, the negative trend of the correlation between growth in height and flower production in any particular year may be ascribed to the differential effect of the environmental conditions on the behaviour in two genes. Conditions which allow full play to the effect of genes for vegetative growth partially inhibit the full manifestation of the effect of the genes for flower production.

SUMMARY

An attempt has been made to find out a mathematical expression for the flowering curves of four varieties of cotton grown at Lyallpur. It was found that the logistic equation of the third degree, viz. $\text{Log}\ \frac{x}{a-x} = A + Bt + Ct^2 + Dt^3$, gave the best fit for the rate of flower production. The average trend of flower production for a large number of years was also found to be significant to the third degree. The relative rate of flower production was found to be a function of time, although Prescott [1922] working on Egyptian cotton found it to be constant.

The relative rate of flower production was high for the indigenous variety, 39 Mollisoni, than for all the acclimatized Punjab-American varieties.

A comparison of the relative rate of growth in height and flower production showed that whenever the rate of growth was higher in any particular variety than in another in any one year, the rate of flower production was also higher in the former. In one variety, however, if the rate of growth was higher in any one year, the rate of flower production was low.

ACKNOWLEDGEMENTS

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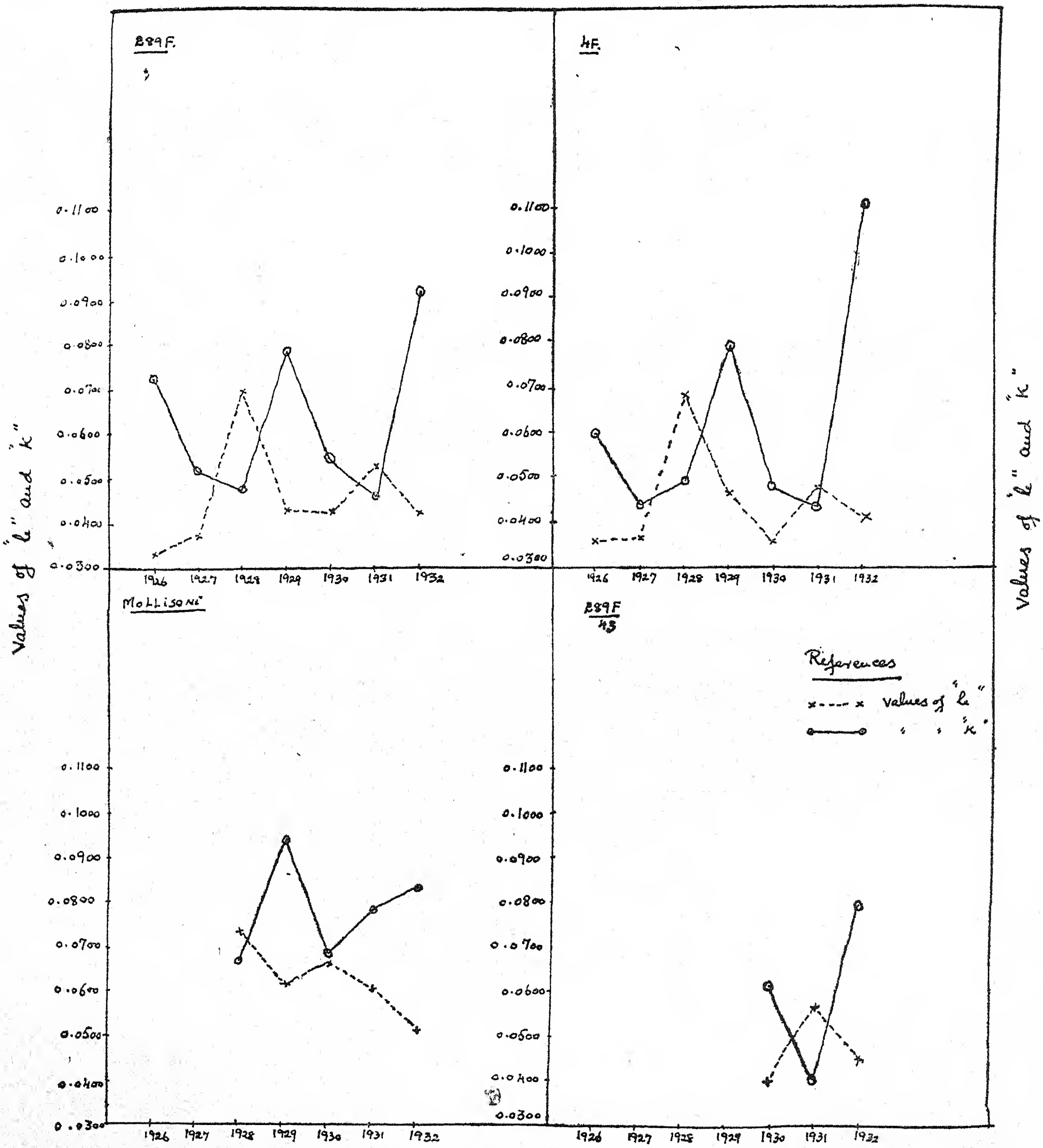

FIG. 4. The relation between the relative rates of growth in height and of flower production

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STUDIES IN THE PRESERVATION OF FRUIT JUICES

III. PREPARATION AND PRESERVATION OF TOMATO JUICE*

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Tomato juice, a product of comparatively recent origin, was first introduced in the American market in 1929, and to-day it is by far the most popular juice. In 1929, only 165 thousand cases (case of 24 No. 2 cans) were produced, whereas due to the expanding consumers' demand the pack rose to nearly 9 million cases in 1936 [Anon, 1936]. Tomato juice like grapefruit juice [Joslyn and Marsh, 1937] was first produced as a means of utilizing the waste from the tomato canning factories in America but at present, however, most of it is made from whole fruits.

In the Punjab, tomatoes are especially prolific in the months of April, May and June and are also available in winter months if protected from frost. In summer months they can be purchased at extremely low prices of a rupee or so per maund of 82 lb. (pre-war) and it was realized that such cheap fruit could be very profitably utilized for the preparation of tomato juice.

Various methods for the manufacture of tomato juice as practised in Western countries are discussed by Sanborn [1938], Cruess [1938, 3], Tressler [1938], Pearce & Ruyle [1938], Anonymous [1931 ; 1939], Joslyn [1937], Kohman [1931 ; 1934], and Joslyn and Marsh [1937]. The effect of different methods of preparation on the quality of the product are also described. The equipment employed is usually of automatic nature and is meant for mass production and is very expensive. In the ensuing investigation, however, an effort has been made to employ simpler type of equipment for production on 'home' as well as semi-commercial scale. Treatment of tomatoes prior to juice extraction, preservation of juice by different methods, changes in theq uality of the product after about two years' storage at room temperature, cost of production, etc. are discussed. As a consequence of a study of these factors, a method for the preparation and preservation of the juice has been described.

Raw material

In the absence of any standard varieties of tomatoes, two types of tomatoes locally known as *desi* and *Peshawari* were used. The fruit of *desi* variety was medium large having a rather irregular outline and of flattened shape usually with corrugations near the stalk end. On the average 4 to 6 fruits weighed to a lb. The fruit of *Peshawari* variety was pear-shaped and was rather small in size weighing on the average 12 to 14 fruits to a pound. Fully mature fruit of deep red colour was used in the experiments described in the sequel and it was found, as stated by Joslyn and Marsh [1937], that small red fruits (*Peshawari* variety) gave relatively a product of better quality than the large-sized fruit (*desi* variety).

Experimental

In order to see the composition of tomato juice (packed in tin and glass containers) available in the market, five samples of the product manufactured by different firms, local and foreign, were analysed for their specific gravity, percentage of soluble solids, sodium chloride and total acidity (as malic acid). The data thus collected are given in Table I. Composition of these samples was kept as a basis for the preparation of experimental lots of tomato juice. In the product finally standardized, the total solids and sodium chloride content which are the main ingredients concerned with the 'body', taste and flavour of the juice, were controlled at a figure of 6·0 and 1·0 per cent respectively.

Table I

Analysis of various brands of tomato juice as obtainable in the local market

Brand of tomato juice	Sp. gravity of juice at 68°F.	Sp. gravity of filtrate at 68°F.	Per cent solids in juice	Salt as sodium chloride in 100 c.c. juice	Total acid as malic in 100 c. c. juice
1. Well-known brand (Foreign manufacture) 1936	1·0240	1·022	5·66	0·89	0·38
2. Ditto 1938	1·0240	1·022	5·66	0·79	0·36
3. Ditto . .	1·0334	1·031	7·99	0·84	0·49
4. Ditto . .	1·0250	1·023	5·91	0·82	0·38
5. Local manufacture	1·0387	1·036	9·27	1·742	0·59
6. Ditto . .	1·0292	1·027	6·95	1·111	0·56

*Parts I and II of this paper have appeared as Misc. Bull. Nos. 32 and 39 of the Imperial Council of Agricultural Research

Preparation of Juice

Tomato juice being a product of recent origin, no recognized standard method for its manufacture has so far been adopted. In Western countries, the method of manufacture varies from plant to plant [Joslyn and Marsh, 1937].

The method of manufacture of tomato juice essentially consists of:

1. Washing and sorting of fruit
2. Trimming of fruit
3. Pre-treatment of fruit prior to juice extraction
4. Extraction of juice
5. Packing and processing

Pre-treatment of fruit prior to juice extraction, methods of extraction of juice and its proper preservation are of prime importance and it is in the manipulation of these processes that opinions differ as to what methods yield the best juice.

1. *Washing and sorting of fruit*

Greatest possible care should be taken in washing the fruit thoroughly to remove dirt and other extraneous matter.

In experimental lots prepared in these laboratories to standardize the product, tomatoes were first soaked in a cement tank in running cold water and finally washed with strong sprays of water. The washed fruit was then sorted, over-ripe and under-ripe fruits were discarded as these yield a juice of poor flavour and colour [Cruess, 1938, 3].

Different types of washing equipment for large-scale production have been described by Joslyn and Marsh [1937] and Tressler *et al.* [1939].

2. *Trimming of fruit*

The fruit after washing and sorting should be carefully trimmed to remove stain, rotten and green or yellow portions, as the inclusion of these adversely affects the quality of the product.

3. *Pre-treatment of fruit prior to juice extraction*

In these laboratories, tomatoes prior to juice extraction, were subjected to the following treatments:

(1) Whole tomatoes (after washing and trimming) were blanched in boiling water for 3-5 min. and (2) tomatoes were 'broken' or crushed as suggested by Lal Singh and Girdhari Lal [1940]—this briefly consisted of passing the trimmed tomatoes in a grape crusher. The crushed tomatoes were then boiled for 3-5 min. In both the treatments heating was done in a steam jacketed kettle [Lal Singh and Girdhari Lal, 1940]. Pre-heating of tomatoes almost completely extracted the colouring matter from the skin and at the same time rendered the fruit soft, thus facilitating the extraction of juice.

Results of a typical experiment carried out to test the efficiency of these two methods of pre-heating the juice in the case of *desi* and *Peshawari* varieties of tomatoes are given in Table II. It will be seen from this table that comparatively higher yields of juice were obtained in the case of chopped or crushed tomatoes, viz. 64·4 per cent (*desi* variety) and 70·0 per cent (*Peshawari* variety) as against 53·0 per cent and 65·0 per cent obtained when tomatoes were blanched as wholes.

Table II

Results of pre-treatment of tomatoes prior to juice extraction

Treatment	*Desi* tomatoes			*Peshawari* tomatoes		
	Yield of juice per cent	Sp. gr. of filtrate	Per cent solids in juice	Yield of juice per cent	Sp. gr. of filtrate	Per cent solids in juice
1. Whole tomatoes blanched in boiling water for about 3-5 min. before extraction	53·0	1·0205	5·27	65·0	1·0228	5·85
2. Tomatoes crushed in cold and boiled for 3-5 min. before extraction	64·4	1·0240	6·16	70·0	1·049	6·16

Blanching of whole tomatoes which would naturally include some trimmed or cut tomatoes, therefore, suffered from an obvious disadvantage in so far as some juicy portion of the fruit from the cut surface diffused into the blanching vessel, resulting in loss of some juice as indicated in the experiment mentioned above. This loss can be considerably avoided if whole tomatoes after trimming are scalded in steam.

Cut-out examination of the two sets of juice prepared under treatments (1) & (2) in Table II, carried out during a storage period of about two years, revealed that the tomatoes crushed and boiled for 3-5 min. yielded a much superior product in respect of 'body', flavour and taste to that obtained by blanching the whole tomatoes.

In regard to the effect of pre-treatment of crushed tomatoes prior to juice extraction on its vitamin content and viscosity, various workers in the tomato juice line like Tressler *et al.* [1939], Sanborn [1938], Tressler [1938], Joslyn [1937] and Cruess [1938, 1], have put forth their views from time to time. Recommendations made by these workers clearly indicate the usefulness of pre-heating the crushed tomatoes before juice extraction, although diversity of opinion exists as to whether the fresh tomatoes should be scalded or blanched as wholes or as pieces.

4. *Juice extraction*

None of the extractors like the 'Indiana Juice Machine' [Tressler, 1938] and the 'non-aerating juice extractor' [Anonymous, 1939] normally used for the extraction of tomato juice were available during the course of this investigtion. Consequently the best use had to be made of the equipment available. During the preliminary stages of this work, the tomatoes under two treatments (Table II) were screened through galvanized iron sieve (1 mm. mesh) covered with a thin muslin cloth [Lal Singh and Girdhari Lal, 1940]. Ordinarily to avoid metallic contamination, non-corrodible metal screens like those of monel metal, stainless steel, etc. should be used, but due to the non-availability of these, the use of galvanized iron sieves could not be avoided—this, however, did not materially affect the quality of the product during storage.

In the final stages of standardizing this product, however, modern 'fruit pulping machine' [Lal Singh, Girdhar Lal & Ishaq, 1943] was available for extracting the juice. This machine is entirely made of stainless steel and has been found to be very efficient for the extraction of juice from preheated tomatoes. The juice extracted by the pulping machine has been found to yield a product of an excellent quality. This machine is now being used very satisfactorily for semi-commercial production and is capable of extracting juice from about 40 maunds tomatoes, per eight hour working day.

5. *Packing and processing of tomato juice*

Juice passing through the pulping machine was immediately raised to boiling point in steam-jacketed kettles. At this stage a quick test was made for determining the total solids content [Cruess and Christie, 1922], which was found to be near about 6·0 per cent in the typical large-scale experiment (Table II).

Sodium chloride content was maintained at 1·0 per cent level by adding common salt just after heating the juice prior to filling. A few preliminary experiments on the preparation of tomato juice on a small scale indicated that addition of about one per cent cane sugar in combination with common salt considerably enhanced the flavour and taste of the juice. Crystalline cane sugar at the above rate (i.e. 1·0 per cent) was added. It was then filled at a temperature of 180°-190° F. in A2 size cans as well as 24 oz. capacity crown top bottles, the two types of containers being sealed in the usual manner and processed as follows:

A2 cans—25 min. at 212° F.

24 oz. bottles—35 min. at 212° F.

The containers were then immediately cooled in running water.

The juice pasteurized and packed in the above manner remained in sound condition even after a storage of about one and a half years, but had one obvious disadvantage that it spoiled within a few hours after opening of the containers as would naturally be the case in any pasteurized sub-acid and unsweetened fruit or vegetable juice. To overcome this difficulty, further experiments were conducted in June 1941. In these experiments chemical preservation by sodium benzoate (in doses of 0·02, 0·05 and 0·1 per cent) in combination with pasteurization was tried, to test whether the keeping quality of tomato juice, after opening the containers, could be improved. This trial indicated that juice preserved chemically by 0·02 and 0·05 per cent sodium benzoate and then pasteurized, had normal taste and that the juice after opening the containers remained in good sound condition for over two months in the laboratory.

There is considerable difference of opinion concerning the methods of packing and processing of tomato juice amongst workers in foreign countries. In this connection interesting observations have been made by workerss like Cameron [1936, 1], Tressler [1938], Pearce and Ruyle [1938], Tressler *et al.* [1939]. They have also outlined different types of packing and processing equipment for large-scale production.

Colour changes in the juice

During the processing and storage of tomato products, the browning of their typical bright red colour is not an uncommon observation. No one has yet satisfactorily explained the causes of this browning, although several possibilities have been put forth by Matlack and Sando [1933].

Literature on the comparative reaction of glass and tin containers on the red colour of tomato products is scanty. In a preliminary experiment conducted in these laboratories in 1937, in which juice from one lot was packed separately in ordinary white glass crown-corked bottles, and in plain and lacquered cans, the following observations were made during a storage period of 1½ year at room temperature.

1. The light red colour of the juice in glass bottles was stable for six to eight months and then gradually changed to deep brown, the intensity of brown colour varying considerably in individual bottles.

2. The juice in tin containers retained its normal bright-red colour during the entire storage period, but acquired a slightly tinny flavour and taste which was not unpleasant. In lacquered cans, however, it became bitter and the lacquer of the can though intact, was almost completely separated from the tin plate and came off even with a slight

touch after the can had been emptied of its contents.

These adverse colour changes in the juice packed in glass may be attributed to, (1) the composition of glass, i.e. its alkaline nature due to the presence of calcium and sodium silicates (as it was observed that addition of even a trace of a week alkaline solution to the freshly prepared tomato juice turned its colour brown), (2) the effect of light, and (3) the effect of air present in the head-space in the bottle.

Further critical study of these colour changes was made in 1939. In these experiments, juice was packed in five different types of bottles of different makes and also in plain tin cans. The glass of each type of bottles was presumed to have different chemical composition. In each of the bottled lots, a few bottles were also covered with black wrappers to cut off the action of light.

Examination of the above sets during one year's storage showed that :

(1) Irrespective of the type of the glass of the bottles of different makes, the juice in some became gradually brown, whereas in others, the change of colour from bright red to brown was not so marked.

(2) Cutting off light had no effect on the colour of juice.

(3) Canned tomato juice retained its normal bright red colour to a marked degree.

From the above, it would seem, therefore, that the colour changes in the bottled and canned tomato juice are probably controlled by the amount of oxygen incorporated in the juice during the process of manufacture. In the case of canned product, oxygen is rapidly fixed by the tin plate [Joslyn and Marsh, 1937], thus resulting in the least change in the colour of the canned juice, whereas in the bottled juice it seemed that varying amounts of oxygen in the air (perhaps incorporated while packing) in the juice affected corresponding change from bright-red to dark brown, as in this case, oxygen is free to oxidize the colour and is not fixed by glass as in the case of tin can.

Carotene and ascorbic acid content

With the equipment available in these laboratories, an attempt was made to determine the loss of carotene and ascorbic acid during different stages of the manufacture of tomato juice (Table III). Tomatoes while passing through five different stages of manufacture, viz. crushing, boiling, sieving, (to remove seeds and skin), heating and finally pasteurizing, were sampled at each stage on four different days for the determination of carotene and ascorbic acid content. Carotene was determined colorimetrically in a Lovibond tintometer employing Steenbock and Boutwell's [1920] method for extraction of carotene, and vitamin C was determined by 2 : 6 dichlorophenol-indophenol by the method of Birch Harris and Ray [1933].

Table III

Loss of carotene and ascorbic acid in tomato juice

Sample	31 May 1939	2 June 1939	3 June 1939	5 June 1939
Carotene content in mg. per kgm. (1,000 gm.) of tomato juice				
I. Crushed	182·4	180·0	211·2	228·0
II. Boiled	139·2	110·4	141·6	153·6
III. Sieved	136·8	105·6	134·4	151·2
IV. Heated	134·4	105·6	134·4	151·2
V. Pasteurized	134·4	108·0	132·0	153·6
Vitamin C mg. ascorbic acid/100 gm. of juice				
I. Crushed	13·85	15·02	16·76	...
II. Boiled	12·41	13·46	12·82	...
III. Sieved	5·27	4·56	4·93	...
IV. Heated	2·68	3·11	3·61	...
V. Pasteurized	3·78	5·01	4·82	...
VI. A well-known foreign brand	...	...	3·72	...

It is seen from Table III that carotene is fairly stable to the action of heat and oxidation by air during the various stages of manufacture, whereas a considerable loss of vitamin C occurs, particularly when the juice is screened through sieve—a process which takes a long time and is responsible for incorporation of a fair amount of air in the product, resulting in the oxidation of ascorbic acid. These observations are in agreement with those recorded by workers like Sanborn [1938], Kohman [1937, 1931], Cruess [1938 ; 1, 2], Joslyn and Marsh [1937], Kohman *et al.* [1930, 1933], and Fellers and Buck [1941] who have shown that in tomato juice oxidation by air is chiefly responsible for losses in colour, flavour and vitamins B and C—while vitamin A is fairly stable under usual process conditions but is removed by filtration.

An interesting phenomenon was observed in the last and the final stage of manufacture, i.e. pasteurization. In the pasteurized juice a comparatively higher ascorbic acid content was present than in the same juice at a previous stage of manufacture, i.e., heating prior to filling and pasteurizing. This may be due to the partial reversion of oxidized ascorbic acid to its active form when the juice was subjected to final heating in a closed container. It will be interesting to note that Mack [1936] observed apparent increase by heating samples of plant tissues before and after extraction in an aqueous medium due to the inactivation of enzyme (ascorbase). Mack and Tressler [1937] explained the apparent increase of ascorbic acid after heating the plant tissues to the formation of physiologically inactive degradation products of

a reducing nature due to the decomposition of dehydro-ascorbic acid. Reedman and Mac Henry [1938] observed a similar increase on heating some vegetables, but found that the ascorbic acid liberated from the 'protein complex' was physiologically active and reduced the indicator.

From the above observations it would appear that unless special equipment is used to prevent the incorporation of air during the entire manufacturing process, a considerable loss in vitamin-C content of tomato juice would take place, whereas vitamin A with ordinary equipment would remain fairly stable.

General recommendations

During all stages of handling, from the extraction to the final packaging, the juice should be protected from contamination with metals, such as zinc, lead, copper, iron, etc. as salts of these metals are toxic. Stainless steel, aluminium, nickel, glass-lined equipment, nickel-copper alloys like monel metal can be safely used.

As a result of the investigation reported above, the following methods for the preparation and preservation of tomato juice is recommended both for home as well as commercial scale.

Step I. Take fully ripe, red-coloured tomatoes, wash thoroughly and trim carefully green and rotten portions, if any.

Step II. (*a*) Home-scale production. Crush the prepared tomatoes with a wooden ladle in a non-corrodible vessel. Boil the crushed mass in an open aluminium vessel on direct fire for 3-5 minutes. Strain through a sieve of 1 mm. mesh made of nickel, monel metal or stainless steel. It is preferable to cover the metallic sieve by a thin muslin cloth. Heat the strained pulp in an open aluminium pan on direct fire and just bring it to quick boil. Avoid over-heating. Remove the pan from the direct fire.

(*b*) Semi-commercial production. Crush the sorted and trimmed tomatoes, by passing them through a crusher consisting of two revolving adjustable grooved wooden rollers placed horizentally. For removing seeds and skin, pass the crushed mass through a pulping or straining machine [Lal Singh, *et al.* 1943]. Heat the strained juice in a steam-jacketed kettle. Bring it to a quick boil, and cut off the steam.

If the right type of raw material is used, the above process yields a product of the right consistency, but in case slightly over-ripe fruit is used, the juice obtained may be too thick, in which case, it is diluted with an appropriate amount of water (only a very small amount of water is required to be added), so that the finished product contains about 6·0 per cent total solids.

Total solids are determined as under. Strain the juice through a thick cloth and determine the specific gravity of the strained juice at 68° F. by a hydrometer. Read the percentage of total solids in the pulp corresponding to the observed specific gravity from the table given in text-books [Cruess, 1938, 3] on the subject.

Step III. To the heated juice as obtained under (*a*) and (*b*), add common salt, and sodium benzoate, dissolved in a small quantity of juice at the rate of one part and 0·02 part by weight, respectively, per 100 parts of juice. Pour the juice while hot in plain tin cans or in sterilized bottles and seal them air tight. Place the bottles or cans in a vessel having a false bottom, cover with water and keep the water boiling for half an hour. Cooking tanks of galvanized iron sheet with steam feed are available for use in large-scale production. Cool the bottles or cans by slowly displacing hot water by running cold water in the cooking tank. This will avoid cracking of bottles. Remove the bottles and cans and store them in cool and dry place.

Crown top bottles should be preferably used for bottling tomato juice; crown cork before use should be sterilized in boiling water for a few minutes. These instructions if strictly adhered to would minimize spoilage known as 'flat sour' giving the product a flat, medicinal flavour which is rather difficult to detect and is caused by thermophilic bacteria.

Cost of production

Cost of production as worked out on the basis of the data collected from the semi-commercial trials conducted over a period of three years, viz. 1939-1941, is summarized in Table IV.

Rates of purchase of raw material, bottles, etc. showed considerable fluctuations from year to year. The above does not include (1) charges on account of supervision and depreciation of machinery, (2) prices at present which have increased considerably on account of war would increase the cost of production proportionately.

Summary

A critical study has been made on the following aspects of the manufacture of tomato juice, viz. (*a*) varieties of tomatoes suitable for juice making. (*b*) washing and sorting of fruit, (*c*) trimming of fruit, (*d*) pre-treatment of fruit prior to juice extraction, (*e*) extraction of juice, (*f*) packing and processing, (*g*) colour changes in the juice as affected by glass and tin container, and (*h*) carotene and ascorbic acid content of juice as affected at different stages of its manufacture. Results are briefly summarized as below:

Fully mature and highly coloured fruits of *Peshawari* variety of tomatoes (fruit rather small

TABLE IV

	Amount	Price	Remarks
		Rs. A. P.	
1. Tomatoes	77 md 33 sr.	225 12 3	Average price of tomatoes per maund in 1939, 1940 and 1941 was Rs. 2-1-3, Rs. 3-4-5 and Rs. 5-2-9, respectively.
2. Common salt	22·5 Sr.	2 4 9	
3. Coal (for boiler)	71 md.	51 9 5	
4. Containers (24 oz. bottle)	2237	335 9 10	Average price of bottles per dozen in 1939, 1940 and 1941 was Rs. 1-10-0, Rs. 2-0-3 and Rs. 1-12-0 respectively.
5. Labour	...	62 12 0	
6. Labels, wrapper, screw, caps and corks	...	56 6 6	
7. Incidental charges like breakage, gloves, soap, cloth, etc.	...	74 5 0	
Total cost for 2237 bottles	...	808 11 9	
Cost per bottle (24 oz.)	...	0 5 9	

and of regular oval shape) gave comparatively a product of better quality than *desi* variety (fruit rather large, round and of irregular shape). In general, the variety of tomato to be used should be 'juicy' rather than 'mealy'.

In a typical experiment, crushing and chopping the tomatoes prior to juice extraction gave higher percentage of juice than that obtained when whole tomatoes, trimmed to remove undesirable portions, were blanched in water, yielding a product much superior in respect of body, taste and flavour to that obtained by blanching whole tomatoes.

About 6 per cent total soluble solids in the juice gave a desirable product. Addition of about 1·0 per cent cane sugar greatly improved the taste and flavour of tomato juice.

Pasteurization in combination with chemical preservation (0·02 to 0·05 per cent sodium benzoate) was found to be the best method of preservation. The juice thus preserved and opened from time to time in the laboratory did not show any signs of spoilage for over two months, whereas juice preserved by pasteurization alone spoiled within a few hours of opening the container.

Colour changes in tomato juice during storage seemed to be controlled by the amount of oxygen or air incorporated in the juice during its different stages of manufacture. Canned juice retained its normal bright-red colour during a storage of about two years. The bottled product, however, showed a browning of varying degrees in different bottles, which was probably due to the corresponding varying amounts of air and oxygen incorporated while packing individual bottles.

Wrapping the bottles with black wrappers to cut off the effect of light had no advantage in arresting the adverse colour changes during storage.

Carotene was fairly stable to the action of heat and oxidation during the different stages of manufacture, whereas considerable loss occurred in ascorbic acid content by oxidation, particularly after sieving the heated tomatoes to remove seeds and skins.

Finally a method for the manufacture of tomato juice on 'home' as well as 'commercial' scale has been described. On the basis of semi-commercial trials conducted over a period of three years, viz. 1939-1941, the cost of production, excluding supervision and depreciation charges worked out at 5 annas and 9 pies per unit of 24 oz. bottles.

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CITRUS ROOTSTOCK TRIALS IN THE PUNJAB

II. THE INFLUENCE OF DIFFERENT ROOTSTOCKS ON THE VIGOUR OF BLOOD RED ORANGE

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(With Plate I and one text-figure)

SINCE the first publication in this series [Lal Singh and Sham Singh, 1942], results of the influence of citrus rootstocks on another scion variety have been studied. These results throw further light on the so-called rootstock influence, which has been discussed already while reviewing literature on the subject in the previous communication. It may be added that Blood Red being one of the most important varieties of sweet orange grown, and its response to various rootstocks especially in the prebearing stage being of sufficient economic importance and academic interest, the publication of the results at this stage of the experiment is amply justified.

The data reported here were collected on the material planted at the Horticultural Research Sub-Station, Montgomery in February 1937 and cover the period from 1937 to 1942.

MATERIAL AND LAYOUT

The rootstock material of the same age and vigour, which was raised both from seed and cuttings, was budded with Blood Red scion in February, 1936. The budded trees were planted up in the orchard in February 1937 by the randomized block method [Fisher, 1935]. Other details regarding the preparation of material and the layout were the same as already reported upon previously [Lal Singh and Sham Singh, 1942]. The various scion-stock combinations under study are given in Table I.

TABLE I

The different scion combinations under trial

Field No.	Method of raising the rootstock	Name of scion-stock combination	No. of trees under study	English equivalents of rootstocks	Specific names
3	Seed.	Blood Red on *Kharna khatta*	18	Nil	*C. karna* Raf.
,,	,,	Blood Red on *Jatti Khatti*	18	Rough lemon	*C. limonia*, Osbeck.
,,	,,	Blood Red on *Mitha*	18	Sweet lime	*C. aurantifolia* Var. Swingle
,,	,,	Blood Red on *Mokari*	18	Citron	*C. medica* Linn.
11	Cuttings	Blood Red on *Kharna Khatta*	18	..	..
,,	,,	Blood Red on *Jatti Khatti*	18	..	..
,,	,,	Blood Red on *Mitha*	18	..	..
,,	,,	Blood Red on *Jullunduri Khatti*	18	Smooth lemon	*Citrus Sp.*

it is clear from the foregoing that the experimental material constituted two sets: In the one case the Blood Red scion was budded on rootstocks raised from seed and, in the other, the same scion was budded on rootstocks propagated by the rooting of cuttings. The two groups of experimental material, thus prepared, were planted separately in two fields and treated as two independent and self-contained experiments. The results of both the trials are embodied in the present communication with a view to study the response of Blood Red trees growing on rootstocks, propagated both from seed and cuttings.

Data collected

Girth measurements of all the trees, correct to the nearest millimetre, were taken at a fixed point above the union year after year for the six-year period from 1937 to 1942. The idea in making these measurements was to study the vigour and rate of growth of Blood Red trees as influenced by the rootstocks on which they were stem-budded.

The data for 1937 relate to the behaviour of one year old 'nursery trees' as at the time of planting in the orchard, those for 1938 as the behaviour of one year old 'orchard trees' and those for 1942 as the behaviour of five year old orchard trees. The year-to-year circumferential measurements of Blood Red trees, as influenced by rootstocks in both the trials are compiled separately in Tables II and III.

Table II

The performance of Blood Red trees growing on certain rootstocks propagated from cuttings

Method of propagation of rootstock	Year of observation	Age of trees in the orchard	Average circumferential measurements in cm. for various rootstocks			
			Kharna khatta	Rough lemon	Sweet lime	Smooth lemon
Cuttings . .	1937	Pre-orchard	3·15	3·17	2·98	2·40
,, . .	1938	One year	5·02	4·96	4·29	3·64
,, . .	1939	Two years	9·70	9·71	7·42	6·28
,, . .	1940	Three years	14·40	16·30	12·1	10·70
,, . .	1941	Four years	17·2	23·6	16·5	16·5
,, . .	1942	Five years	20·0	31·5	21·4	23·1

Table III

The performance of Blood Red trees growing on certain rootstolks propagated from seed

Method of propagation of rootstock	Year of observation	Age of trees in the orchard	Average circumferential measurements in cm. for various rootstocks			
			Kharna khatta	Rough lemon	Sweet lime	Citron
Seeds . .	1938	One year	2·53	3·34	2·97	3·70
,, . .	1939	Two years	5·16	6·68	5·40	5·45
,, . .	1940	Three years	10·07	12·52	9·05	8·62
,, . .	1941	Four years	14·7	19·2	13·8	12·7
,, . .	1942	Five years	19·1	27·1	18·8	15·8

Methods employed

The mean figures for girth as influenced by different rootstocks are compiled in Tables II and III. The data show the yearly development of Blood Red trees, which depends upon (*a*) inherent growth capacity of the trees in association with various rootstocks technically known as 'relative growth rate' and (*b*) the seasonal and other accidental variations obtaining from year to year. Therefore, to make an exhaustive and accurate study of the developmental data collected, both aspects of the problem were duly considered.

To study growth rate, the logrithmic values of the girths taken at different intervals were calculated and plotted. The curves, so obtained, are shown graphically in Fig 1. These curves, being linear, are best studied by the exponential equation $W_1 = W_{oe}{}^{rt}$ which was devised by Blackman [1919] and subsequently used widely by several workers [Afzal and Iyer, 1934].

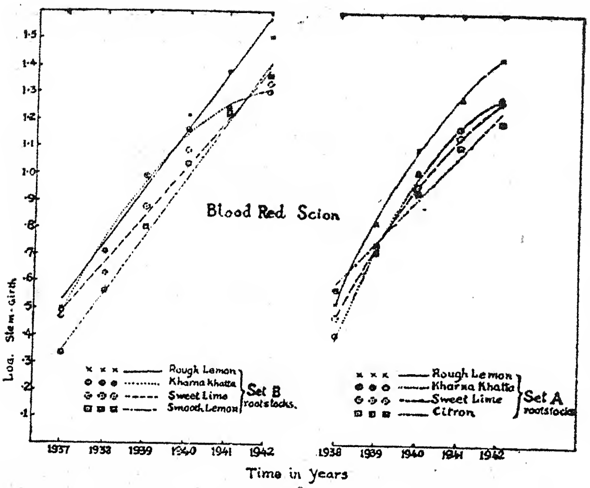

FIG. 1

The notation of the above equation used here is as:

$X = Ae^{bT}$, where

X = girth in cm.

A = theoratical girth at the start in the orchard

T = time in years from the beginning of the experiment

b = relative rate of growth per year

The above equation can be transformed as under:

$$\text{Log}_{10} X = \log_{10} A + bT \log_{10} e$$
$$= \log_{10} A + b . \log_{10} e\, T$$
$$\text{or} \quad y = a + KT \text{ where, } a = \log_{10} A$$
$$\text{and } b = \frac{K}{\log_{10} e.}$$

PRESENTATION AND DISCUSSION OF RESULTS

(A) *Comparison of data in Tables II and III*

A cursory comparison of the data in Tables II and III brings out prominently the fact that Blood Red trees on rootstocks propagated from cuttings (Table II) remained bigger-sized during the first five years than the corresponding trees on rootstocks raised from seed (Table III). At the time of planting in the orchard, in 1937, one year old trees on rootstocks raised from seed were so thin that their girth measurements could not be recorded by steel tape. And even after five years of their existence in the orchard (1942-data) the trees on rootstocks raised from cuttings remained bigger-sized than those on rootstocks raised from seed. This showed that initial advantage of vigour in case of rootstocks raised from cuttings persisted even after five years of orchard life, although, as would be seen later under item (C), the trees on seedling rootstocks are likely to outgrow those on cutting rootstocks in view of their higher rate of growth.

(B) *The yearly growth increment in girth*

The yearly growth increment in girth made by Blood Red trees in both the experiments was identical and interesting. Therefore, in the interest of brevity, the data for trees on rootstocks raised from cuttings alone are given in Table IV for detailed discussion.

The data for 1937 (col. 3, Table IV) collected at the time of planting the trees in the orchard, showed that in the pre-orchard or nursery stage, the Blood Red trees on rough lemon and *kharna khatta* made better growth than on the remaining two rootstocks. The data for 1938, being the year immediately following the transplanting of trees in the orchard, showed that there had been a considerable set back to growth on all the rootstocks. This happened mainly due to the fact that the trees took considerable time to settle down in new environment and to regenerate enough root system to put on new growth. However, the shock of transplantation appeared to be borne equally well by all the rootstocks as the growth, made during that year, was in the same order as that made in the preceding year. Furthermore, the root system of large-sized nur-

TABLE IV.

The mean annual increment in girth in cm. Scion variety—Blood Red

Growing season	Age of trees in the orchard	Year of observation	Rootstocks			
			Kharna khatta	Rough lemon	Sweet lime	Smooth lemon
1936	Pre-orchard	February 1937	3·15	3·17	2·98	2·40
1937	One year	February 1938	1·87	1·79	1·31	1·24
1938	Two years	February 1939	4·68	4·75	3·13	2·64
1939	Three years	February 1940	4·70	6·59	4·68	4·42
1940	Four years	February 1941	2·80	7·3	4·4	5·8
1941	Five years	February 1942	2·80	7·9	4·9	6·6

sery trees is apt to be severed to a greater extent at the time of removal from the nursery as compared with small-sized trees, because the earth balls are generally of the same size in each case. And this fact may, in some cases, slightly upset the normal behaviour of orchard trees during the year immediately following transplanting but, in the experiments here under consideration there was no evidence of even such an influence having been introduced.

In the second and third orchard years, the trees on various rootstocks followed the same course of development and growth as in the first year except those on *kharna khatta* in the third year. It is also clear that whereas the amount of growth made by trees on rootstocks other than *kharna khatta* was increasing every year, that made by trees on *kharna khatta* retarded perceptibly. It may be mentioned in this connection that all the trees on *kharna khatta* in all the six replicates showed signs of splitting of bark below the union in 1939 and four out of 18 trees even died by the end of that year. The surviving trees dropped a large amount of foliage every winter (Plate I) and this may probably be termed as a case of delayed incompatibility.

In the fourth year, in 1941, the condition of trees on *kharna khatta* deteriorated considerably, and this is corroborated by the figure for mean annual growth increment, which works out at 60 per cent of the preceding year. It may be added that trees on all the rootstocks were bearing crop during that year, but nevertheless, those on rough lemon and smooth lemon made still greater annual increment in growth. In the fifth year, the condition of trees on *kharna khatta* deteriorated still further so much so that even trees on sweet lime (a dwarfing rootstock) had outgrown them. The data for yearly growth increment in girth, discussed above, brought out glaringly the fact that *kharna khatta* was the most unsuitable rootstock for Blood Red scion. And, in view of the performance of this rootstock with regard to the condition and vigour of Blood Red trees over a period of six years, it can be asserted that Blood Red scion should not be propagated on *kharna khatta*.

The above noted conclusion has a special significance as it is contrary to the established behaviour of *kharna khatta* rootstock with most other species of citrus. Even in case of *C. sinensis* Osbeck to which Blood Red also belongs, this rootstock is known to have produced trees of the highest vigour. Thus a particular rootstock may differ in its influence not only with different species but even with different varieties belonging to one and the same species. In other words, in determining the rootstock influence in case of citrus one should not be content merely with the study of such influence with different species, but one should go a step further in that such an influence should be studied for all such important commercial varieties belonging to a species as appear to possess marked differences in morphological development like Malta local and Malta Blood Red varieties of *C. sinensis*, Osbeck.

(C) *The statistical treatment of the data given in Tables II and III (pertaining to both the field trials)*

In order to study in detail the data given in Tables II and III a general curve up to the quadratic was fitted to the data by the method of orthogonal polynomials, which was finally reduced to the significant constants only. The analysis of variance of the sum of squares contributed by these regression coefficients in the curve was compiled separately for the data in Tables II and III. That for Table II is given in Table V, which pertains to Blood Red trees growing on rootstocks raised by the rooting of cuttings.

From Table V it is evident that the linear regression is significant for all the treatments, but in case of *kharna khatta* even the quadratic component is also significant. The equations so obtained are given below:

Rough lemon :— $y = \log x = +0{\cdot}3202 + 0{\cdot}2069\ t$

Kharna khattta : — $y = \log x = +\ 0{\cdot}1478 + 0{\cdot}3555\ t$-0 0272 t^2

Sweet lime :— $y = \log x = +0{\cdot}3098 + 0{\cdot}1785\ t$

Smooth lemon :— $y = \log x = +0{\cdot}1799 + 0{\cdot}2034\ t$

The values (K) as given by the equations are :—

Rough lemon $= +0{\cdot}2069$; *Kharna khatta* $= +0{\cdot}3555 - 0{\cdot}0543\ t$; **Sweet lime** $= +\ 0{\cdot}1785$; **Smooth lemon** $= +\ 0{\cdot}2034$

The above values show that K and consequently b or the relative rate of growth of the trees remains constant on three rootstocks namely rough lemon, sweet lime and smooth-lemon but it goes on decreasing in case of *kharna khatta*. The values for A and b, characteristic of the exponential equation are given in Table VI.

The values for A show that one year after budding, the vigour of Blood Red nursery trees was comparatively far better on *kharna khatta* rootstock than on others; it was about the same on rough lemon and sweet lime, but was the least of all on smooth lemon. The explanation for this lies in the fact that, during the same interval in the nursery, rootstock seedlings of

Blood Red trees on *kharna khatta*
Note defoliation in all the three trees in the row

TABLE V

Analysis of variance of the sum of squares due to regression coefficients

	D. F.	Rough lemon		*Kharna khatta*		Sweet lime		Smooth lemon	
		S. S.	M. S.	S. S.	M. S.	S. S.	M. S.	S. S.	M. S.
Linear	1	0·74948	0·74948‡	0·47883	0·47883‡	0·55775	0·55775‡	0·72372	0·72372‡
Quadratic	1	0·00899	0·00899	0·02752	0·02752†	0·00487	0·00487	0·00162	0·00162
Residual	3	0·00379	0·00126	0·00388	0·00129	0·00338	0·00113	0·00216	0·00072
Total	5	0·76226	..	0·51023	..	0·56600	..	0·72750	..

† Significant at 5 per cent ‡ Significant at 1 per cent

TABLE VI

	A	b*
Rough lemon	2·090	0·4765±0·0311
Kharna khatta	2·519	0·3809±0·0486
Sweet lime	2·041	0·4111±0·0249
Smooth lemon	1·513	0·4682±0·0169

* The value of *b* is obtained from the average value of *k* for all the years to facilitate comparison

kharna khatta attained the greatest height and vigour whereas those of smooth lemon remained the weakest of all. In view of this, the initial advantage of vigour characteristic of different species of rootstocks was reflected in the early years of budded trees. But, as the vigour of an unworked rootstock is no criterion of its vigour as a rootstock when grafted or budded with a scion variety, the response of the scion variety to growth and development would ultimately depend upon the degree of compatibility between the two symbionts.

The values for *b* or the relative rate of growth, on the other hand, show that Blood Red trees on rough lemon and smooth lemon rootstocks are characterized by a much higher growth rate than corresponding trees on sweet lime and *kharna khatta*. The differences being highly significant, it can be safely asserted that rough lemon and smooth lemon rootstocks are associated with vigorous growing trees of Malta Blood Red selon, whereas trees of the same scion would remain stunted in growth if worked on sweet lime and *kharna khatta*. In fact, on *kharna khatta*, the relative growth rate is on the decrease, and as stated before some trees have even died as a result of delayed incompatibility of Blood Red scion with this rootstock. For all practical purposes, therefore, *kharna khatta* may be regarded to have proved unsuitable as a rootstock for Blood Red scion even at this early stage of the experiment.

As stated before, a general curve was also fitted to the data is Table III. The analysis of variance of the sum of squares contributed by the regression coefficients in the curve was compiled and is shown in Table VII.

TABLE VII

Analysis of variance of the sum of squares due to regression coefficients

	D. F.	Rough lemon		*Kharna khatta*		Sweet lime		Citron	
		S. S.	M. S.	S. S.	M. S.	S. S.	M. S.	S. S.	M. S.
Linear	1	0·5184	0·5184‡	0·4886	0·4886‡	0·4041	0·4041‡	0·2652	0·2652‡
Quadratic	1	0·0108	0·0108‡	0·0191	0·0191†	0·0061	0·0061‡	0·0022	0·0022
Residual	2	0·00018	0·000089	0·00057	0·00028	0·000019	0·000009	0·00109	0·00055
Total	4	0·52938	..	0·50827	..	0·410219	..	0·26849	..

The above table shows that S. S. due to linear and quadratic regressions were significant in all cases except for citron, where only the linear component was significant. The equations, so obtained, are given below:

Rough lemon :—$y = \log x = +0{\cdot}1546 + 0{\cdot}3947\,t - 0{\cdot}0278\,t^2$.

Kharna khatta :—$y = \log x = -0{\cdot}0085 + 0{\cdot}4429\,t + 0{\cdot}0370\,t^2$

Sweet lime :—$y = \log x = +0{\cdot}1663 + 0{\cdot}3260\,t - 0{\cdot}0208\,t^2$

Citron :— $y = \log x = +0{\cdot}4200 + 0{\cdot}1628\,t$

The above equations indicate that the rate of growth remains constant for citron but in case of other stock treatments the rate of growth

goes on decreasing, thus the rate of change of y can be expressed as follows:

Rough lemon $\frac{dy}{dt} = + 0\cdot3947 - 0\cdot0557\, t$

Kharna khatta $\frac{dy}{dt} = + 0\cdot4429 - 0\cdot0739\, t$

Sweet lime $\frac{dy}{dt} = + 0\cdot3260 - 0\cdot0417\, t$

Citron $\frac{dy}{dt} = + 0\cdot1628$

The above equations show that the rate of growth of trees on *kharna khatta* rootstock decreased more rapidly than on the remaining rootstocks. In order to compare the values for rate of growth of trees growing on different rootstocks, the averages were worked out and thus the rates were 0·2277, 0·2210, 0·2010 and 0·1628 for rough lemon, *kharna khatta*, sweet lime and citron respectively. From this it is evident that the relative rate of growth was the least when citron was used as the rootstock. This rootstock, it may be noted, was used in this experiment in place of smooth lemon, used in the other discussed before.

The results of both the trials have shown that rough lemon gave outstandingly the best results for Blood Red scion as compared with others, smooth lemon coming next, and it is also likely that the former rootstock may maintain its present behaviour in later years as well. Even more significant is the fact that *kharna khatta* which proved incompatible with Blood Red scion in both the trials, should not be used in propagating this variety. Thus although the question of rough lemon as the most suitable rootstock for Blood Red remains yet to be settled finally in view of the long range nature of these experiments, the fact that *kharna khatta* and citron are unsuitable is proved even at this early stage.

Summary and conclusions

1. The influence of certain rootstocks, propagated both from seed and cuttings, on the vigour and condition of Blood Red trees was studied for a period of six years.

2. Rough lemon gave outstandingly the best results with Blood Red scion as compared with other rootstocks, smooth lemon coming next.

3. *Kharna khatta* proved incompatible with Blood Red scion and even at this early stage of these trials, it can be asserted that this rootstock should not be used for propagating this variety.

4. Citron is yet another rootstock which proved unsuitable in case of Blood Red scion.

5. A particular rootstock may profoundly differ in its influence on scion varieties belonging to one and the same species. For instance, Blood Red on *kharna khatta* had completely failed whereas Malta local on the same rootstock is doing very well indeed.

6. Based on stem-girth measurements as these conclusions are, they may be taken with some reserve, as they may have to be revised when more data on new characters are available.

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PLANT QUARANTINE NOTIFICATION

Notice No. 3 of 1943

THE following plant quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi, for loan.

United States Department of Agriculture

1. White-Fringed Beetle (Quarantine No. 72) Revision of Quarantine and Regulations.
2. Service and Regulatory Announcements—January—March 1943.
3. Service and Regulatory Announcements—Index for 1942.

GIPD—3S—444 IC of AR—30-9-44—600.

ORIGINAL ARTICLES

SOILS OF THE DECCAN CANALS

VI. STUDIES IN AVAILABILITY OF NITROGEN IN FARMYARD MANURE AND SULPHATE OF AMMONIA WHEN APPLIED TO VARIOUS SOIL TYPES

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(With two text-figures)

Considerable differences of opinion exist to-day regarding the nature of response of farmyard manure in soil. Field experiments conducted on the same crop in different parts of India show contradictory results [Rege, 1941], while experiments carried out at the same place on different crops do not always lead to the same conclusion [Sahasrabudhe, 1934]. Various aspects of this complex problem, therefore, require careful investigation in order to understand the processes responsible for such a behaviour so that a rational system of manuring can be worked out for different soils and crops in India.

It is a common experience with agricultural scientists that the fertilizing value of farmyard manure is always much less than what it should be if all the nitrogen in it were available to the plant. Workers in different countries have found nitrogen utilization from farmyard manure by plants to the extent of 0 to 40 per cent in pots and 7 to 93 per cent under field conditions [Jensen, 1931]. This incomplete uptake of nitrogen from farmyard manure by plants can be generally attributed to its incomplete mineralization in soils and to the varying feeding capacities of different crops. It is already known that the nitrogen in manures is made available to plants through micro-organic activities of soils which are governed by a number of factors, of which the following are important: (a) temperature, (b) moisture, (c) physico-chemical properties of the soil, (d) nature and amount of energy materials present and (e) micro-flora. The last three factors are intimately linked up with each other and find their full expression in a 'soil type'. Brown [1922] has rightly pointed out in this connection that 'when we consider various factors which influence bacterial development in soils and then remember how these factors vary in different soils, it will be evident that bacteriological results will be influenced to a large extent by the soil type. Many experiments have shown this fact and, while it is often difficult if not impossible to distinguish and disentangle the various factors which are closely allied, it is worthy of note that the variations in results may very generally be traced back to the soil type, other conditions being the same.' Bennet and Allison [1928] have stressed the importance of soil type work as a basis of manuring. Similarly, Iowa Research Station has been conducting a series of manurial experiments on their important soil types as a result of which valuable results are now available, which serve as guides for the manurial recommendations for different soil types of Iowa [Brown, 1936].

In this paper the results are discussed of a biochemical study on the response of (i) a quick-acting fertilizer-sulphate of ammonia and (ii) a slow-decomposing bulky manure—a typical local sample of farmyard manure, on some important genetic soil types belonging to the broad group of black cotton soil of India. It is also indicated how this kind of study has thrown some light on the question of manuring of these soils from the point of view of their responses to crops.

Experimental

Five soil types commonly found on the canals of the Bombay-Deccan were selected for this study. These soils were classified previously at this station [Basu and Sirur, 1938] according to the modern genetic method of soil survey into eight types which were chronologically named as A to H. The morphological features of the soil types A to E, employed in the present investigation, are briefly indicated in Table I, while certain important soil properties are given in Table II.

*This scheme is partly subsidized by the Imperial Council of Agricultural Research

TABLE I

Morphological features of soil types

A Type	B Type	C Type	D Type	E Type
Two horizons of uniform black colour with a tinge of red, the upper 12 in. or so having an excellent crumb structure and usually interspersed with roots ; the lower horizon faintly laminated but porous ; clay loam. Soil depth 2-4 ft. Below *murum* of medium hardness impregnated with lime.	Characterized by 3 horizons : the first about 20 in. thickness, greyish black colour with brown shade, with a more or less cloddy structure, clay loam, the second mottled horizon brown intermingled with black soil brown increasing with depth, thickness 20 to 30 in. silt loam ; follows a reddish-brown coloured horizon with concretions of lime and silicate material. Deep soil extending up to 4-10 ft. with *murum* below.	Consists of a single horizon, of deep black coloured soil, lumpy structure, getting moister and strickier with depth; black concretions of lime usually present in lower layers, clay loam. Depth of soil about 3 to 12 ft. overlying thoroughly decomposed *murum* almost like sand, heavily charged with lime.	One horizon, dark grey with brown shade, loose and granular, with faint structure appearing in lower depths (from 12 in. onwards) which attains distinct lamination in the lowest layer loam. Intervening between the soil and the *murum* below is a lime band of dirty white colour and of varying thickness, soil depth 2-3 ft.	An upper fairly friable horizon of about 12 in. depth and of dull greyish black colour but of definitely clayey consistency, followed by a markedly compact second horizon having a slightly darker colour and laminated structure ; soil depth 2½-5 ft. Below hard *murum* grey and yellow, with gluconite.

TABLE II

Physico-chemical properties of soil types

(0-12 in. depth)

Soil types	Maximum water holding capacity per cent	Total bases in m. e. per cent	Per cent sodium saturation	*p*H	Total				C/N	Humus per cent
					P_2O_5 per cent	K_2O per cent	N per cent	C per cent		
A .	81·20	79·20	2·23	7·95	0·092	0·555	0·051	1·09	21·4	1·49
B .	65·00	63·53	1·77	8·36	0·042	0·313	0·062	0·83	13·4	1·34
C .	66·54	69·82	7·75	8·50	0·062	0·077	0·047	1·02	21·7	1·25
D .	71·94	65·58	2·37	8·00	0·065	0·532	0·058	1·10	19·0	1·56
E .	79·00	78·93	1·12	7·95	0·078	0·964	0·062	1·17	18·9	1·09

It will be noticed that morphologically both C and E types are inferior to either of the types A, B or D. From the points of view of both moisture holding power and total exchangeable bases, A and E types are superior to the others. Similarly, both *p*H and sodium saturation indicate the poor condition of C type while *p*H is to a certain extent higher in B type. Carbon/nitrogen ratio, however, places the B type in a much better position than the rest of the types. The types D, A and B are slightly better supplied with humus when compared with the rest.

The farmyard manure used in the experiment was a composite sample of 15 typical manures collected locally which on analysis gave results, shown in Table III.

It will appear from the analysis that the sample of manure is fairly rich in nitrogen possessing a moderately low C/N ratio and thus can be taken as a properly rotted and mature sample.

PROCEDURE

The experiment was conducted in glazed earthenware pots (1 ft. diameter x 1 ft. height)

TABLE III

Composition of the manure sample

Moisture per cent	Loss on ignition per cent	Humus per cent	Carbon per cent	Nitrogen per cent	C/N per cent	Bacterial number in mg.
8·85	34·70	5·30	13·64	0·96	14·2	16·88

using 10,000 gm. or air dried soil in each case. The following treatments were used:

(i) Control—no treatment.

(ii) Farmyard manure—one per cent of the soil employed on an oven-dry basis.

(iii) Sulphate of ammonia—to supply N as in (ii).

The soil moisture was kept up at 50 per cent of the maximum water-holding capacity. Representative soil samples for the various determinations were taken after thorough mixing of the soil at ten-day intervals just before the addition of water. The required quantity of water was added to the soils with proper stirring and the packing adjusted uniformly in all the pots. Care was also taken to keep the time of sampling, water addition and plating for bacterial work constant during the entire period of the experiment, i.e. 120 days. The periodical soil samples were subjected to the following determinations: (i) moisture, (ii) bacterial number, (iii) ammonia, and (iv) nitrate. Total nitrogen and humus were determined at start and after 120 days.

The following analytical methods were used:

Bacterial number was determined by the plate method using the agar medium of Thornton [1922].

Ammociacal nitrogen was estimated by Olsen's method [Wright, 1934].

Nitrate nitrogen was determined by the Phenol-disulphonic acid method recommended by A.O.A.C. [Wright, 1934].

Total nitrogen was determined by the usual Kjeldahl method modified by Bal for clay soils, [Wright, 1934].

Organic carbon was determined by the wet-combustion method modified to suit the Deccan soils [Basu and Vanikar, 1942].

Humus was determined by Sigmond's method by extracting the soil with N/10 sodium carbonate [Sigmond, 1927].

Maximum water-holding capacity was found out by allowing the soil to absorb water in a Flugg cylinder.

PRESENTATION OF DATA

The data on bacterial number and nitrate are graphically represented in Figs. 1 and 2, those of ammonia are given in Table IV, while changes in total nitrogen and humus are shown in Table V.

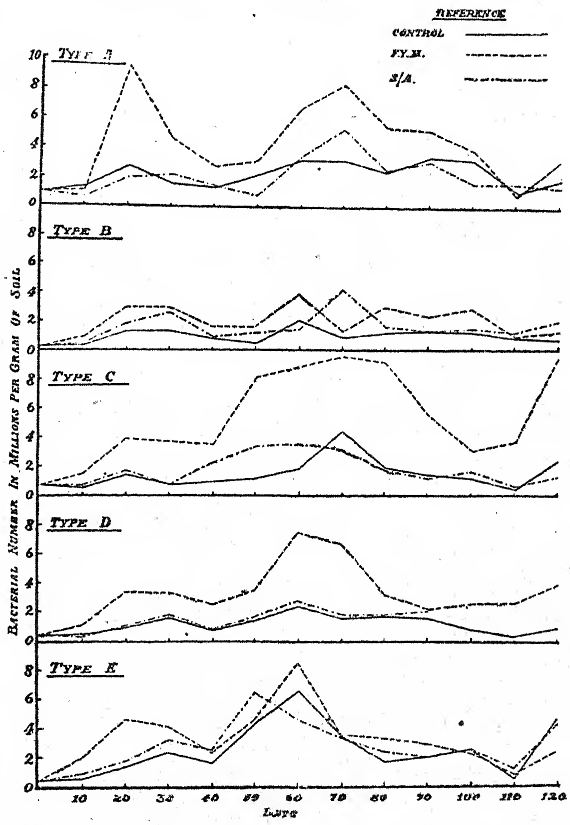

FIG. 1. Periodic fluctuations in bacterial number

Bacterial numbers. In the control soils the bacterial numbers show rises and falls in all cases as a result of periodical wetting and drying of the soil but the magnitudes of these fluctuations are different in different types. Within a period of 120 days two peaks are attained by all soils one between 20 to 30 days and the second between 50 to 80 days from start, the latter being generally of a greater magnitude than the former. After about 110 days the bacterial numbers show a further tendency to rise. Among the soils B type exhibits comparatively poor values in all stages whereas E type

shows very high values on several occasions. The general trend is, however, more uniform in A type demonstrating fairly high numbers throughout. The average figures of bacterial number show the following descending order: E>A>C>D>B.

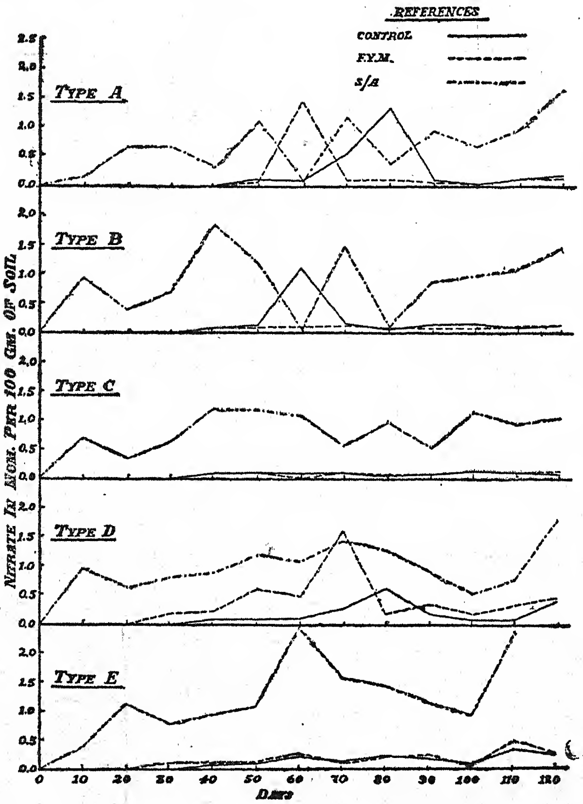

FIG. 2. Periodic fluctuations in nitrate nitrogen

The responses of bacterial numbers to treatments are very characteristically shown in Fig. 1. It will be observed that very good responses with farmyard manure treatment to bacterial numbers are obtained with C and D types while in A type a high value is attained at an earlier date. This effect is also shown in B type to a fair extent while in E type the increase in bacterial number due to addition of farmyard manure is very little. The percentage increases in average bacterial numbers over those of the control are in the order of C (301) > D(209) > B(126) > A(107) > E(32), the figures within brackets indicating the actual percentage increases. With sulphate of ammonia application the increases in bacterial numbers are much smaller and show the following descending order: B(75)>D(29)>C(22)>E(11)>A(—5). These latter results indicate that the soil bacteria as determined on Thornton's agar are only slightly stimulated by addition of an inorganic nitrogenous fertilizer like sulphate of ammonia.

Ammonia. With regard to ammonical nitrogen the fluctuations are less pronounced than those of the bacterial numbers. Usually the peak periods are exhibited by soils when the bacterial numbers are low but this is not invariably true in all cases. Among the control soils, D type shows an early rise in the value (20th day) but remains generally low in later periods. The type B remains fairly high throughout with a peak at a later period (100th day) whereas A type shows an early and a late peak-periods. From the average contents of ammonia it is seen that A, B and D types are superior to either C or E types. With addition of farmyard manure only A and E types show some responses (i.e. 10 and 12 per cent increase respectively over the controls), C type does not show any change in the value while in both D and B types there are actually lowering in the average values of ammonia (25 and 7 per cent lowering respectively). With the application of sulphate of ammonia there are in all cases sharp falls in the values of the initial ammonia contents till 20 to 30 days with very little rise afterwards excepting in the case of A type which shows some increases on the 30th and 100th days.

Nitrate. Under the moisture conditions of the experiment the nitrate nitrogen figures are usually lower than the ammonical nitrogen in all soils; the ratios of ammonia/nitrate in the untreated soils being 4·8, 6·0, 10·0, 5·8 and 3·4 for the types A to E respectively taking the average figures into consideration. It will be evident from Fig. 2 that in the untreated soils there are very little fluctuations in nitrate, pronounced increases being only noticed in B, A and D types, B type showing earlier nitrate production (60th day) than the others (80th day). The average figures, however, indicate only a slight superiority of A over B, D and E while C is poorest in this respect. With addition of farmyard manure only A and D types show any pronounced response in nitrate production and the peak periods are earlier than those in the control soils. The order of response (both positive and negative) with farmyard manuring is as under:

D(138)> E(20)> A(—15) >C(—17)> B(—62),

the figures in the brackets showing the percentage increase or decrease in average nitrate figures over those of the control untreated soils.

Very marked improvements in the nitrate production is observed with sulphate of ammo-

TABLE IV

Ammoniacal nitrogen in different soil types at ten-day periods and their averages
Mg. per 100 gm. of oven-dry soil
(Average for 12 occasions excluding the original values)

Soil types		A			B			C			D			E		
Serial No.	No. of days after start	Control	F.Y.M.	S/A.	Control	F.Y.M.	S/A.	Control	F.Y.M.	S/A.	Control	F.Y.M.	S/A.	Control	F.Y.M.	S/A.
1	0	0·44	1·39	11·89	1·16	2·11	12·61	0·52	1·47	11·97	0·11	1·06	11·56	*Nil*	0·95	11·45
2	10	0·81	1·13	5·83	0·97	0·97	7·23	0·71	0·71	6·63	0·72	0·86	6·19	0·77	0·62	4·16
3	20	*Nil*	0·74	1·33	1·21	0·54	4·29	0·27	0·27	4·15	4·28	1·93	0·69	0·15	0·58	0·29
4	30	1·60	1·45	2·47	1·28	1·15	0·90	0·66	0·40	0·79	1·22	1·08	0·27	*Nil*	0·14	0·14
5	40	0·63	0·79	0·79	0·57	1·00	0·86	0·56	0·56	0·84	0·73	0·73	0·73	0·48	0·64	0·64
6	50	0·95	0·63	0·79	0·79	0·53	0·53	0·52	0·52	0·66	0·57	0·86	0·86	0·59	1·92	1·04
7	60	0·59	0·59	0·59	0·95	0·68	0·95	0·71	0·85	0·42	0·44	0·15	0·58	0·15	*Nil*	0·15
8	70	0·65	0·97	0·65	0·70	0·97	0·97	0·81	0·54	0·54	0·56	0·56	0·98	0·15	0·60	0·60
9	80	0·99	0·71	0·56	0·66	0·92	0·79	0·54	0·67	0·67	0·54	0·13	*Nil*	0·56	*Nil*	*Nil*
10	90	0·80	0·96	1·12	0·97	0·97	0·70	0·70	0·83	0·42	0·44	0·59	0·59	2·00	0·77	0·62
11	100	2·28	2·43	2·13	2·16	1·35	0·54	0·69	0·55	0·55	0·55	0·55	0·41	0·58	0·58	0·44
12	110	0·76	1·22	1·06	0·67	1·06	0·13	0·27	0·40	0·67	0·57	0·57	0·57	0·14	0·43	0·29
13	120	1·40	1·09	1·40	0·83	0·56	0·83	0·71	0·99	0·57	0·56	0·42	1·55	0·60	0·60	1·64
	Average	0·96	1·06	1·56	0·96	0·89	1·56	0·60	0·61	1·41	0·93	0·70	1·12	0·51	0·57	0·83

nia application, which is specially noticeable in the case of C and E types. The percentage increases in the average nitrate contents from those of the control, exhibit the following descending order: C(1330) > E(820) > D(540) > B(470) > A(260), the figures in brackets showing the actual percentage increase. In this case although nitrate-nitrogen is formed in all soils the rapidity with which the maximum nitrification takes place varies considerably with different types. This aspect of the subject will be discussed later.

Mineral nitrogen levels in soils. If the average mineral nitrogen (ammonia plus nitrate) levels are considered we find that without any treatment the soil types A, B and D are generally far richer than the E or C types, the actual order being A (100) > B(96·5) > D(94·0) > E(56·9) > C(56·9), the figures in brackets indicating the percentages when A is taken as 100. With farmyard manure treatment, the order of levels of mineral nitrogen in different types is more or less similar, viz. A (100) > D (87·8) > B(77·2) > E(60·9) > C(53·7). Finally with the addition of sulphate of ammonia, the actual mineral nitrogen levels in all soils are very much enhanced but the differences in the actual levels are not so marked, the order being B(100) > A(92·3) > C(91·9) > E(89·4) > D(86·6), taking the highest figure of B type as 100. The general superiority of the types A and B over C and E in maintaining a higher average level of mineral nitrogen is shown in all cases.

Changes in total nitrogen and humus. From Table V it will be seen that the initial nitrogen contents of the different cotrol soils were in the following descending order: B, E > D > A > C. The final values of total nitrogen after 120 days indicate that with the exception of A type all soils have lost varying amounts of nitrogen as a result of periodic wetting and partial drying. It is curious to find that A and E types show a distinctive behaviour in this respect, A type having actually gained 56 per cent nitrogen while E type has lost only a negligible amount. The types B, C and D have lost between 20 to 30 per cent approximately. As can be expected, the losses in nitrogen have been the greatest with the sulphate of ammonia treatment, the highest loss (45·6 per cent) being suffered by the C type, while E type has shown the least loss (19·4 per cent). With the addition of farmyard manure the losses of nitrogen are of much smaller order, the highest loss being 21·3 per cent in A type and the lowest 12·3 per cent in C type. The loss in nitrogen is in general much lower in E type than either in B or D type under all cases.

TABLE V

Nitrogen and humus in different soil types, original and after 120 days

Soil type	Treatment	Nitrogen			Humus		
		Original	Final	Per cent increase or decrease	Original	Final	Per cent increase or decrease
A	Control	0·051	0·080	56·9	1·49	0·15	—89·9
	F. Y. M.	0·061	0·048	—21·3	1·54	0·18	—88·3
	S/A	0·061	0·041	—32·8	1·49	0·19	—87·2
B	Control	0·062	0·049	—21·3	1·34	0·79	—41·0
	F. Y. M.	0·072	0·059	—18·1	1·39	0·71	—48·9
	S/A	0·072	0·047	—34·7	1·34	0·78	—41·8
C	Control	0·047	0·035	—25·5	1·25	0·68	—54·4
	F. Y. M.	0·057	0·050	—12·3	1·30	0·61	—53·07
	S/A	0·057	0·031	—45·6	1·25	0·40	—32·0
D	Control	0·058	0·040	—31·0	1·56	0·41	—73·7
	F. Y. M.	0·068	0·055	—19·1	1·61	0·38	—76·4
	S/A	0·068	0·043	—36·8	1·56	0·41	—73·7
E	Control	0·062	0·058	—6·5	1·09	0·38	—65·2
	F. Y. M.	0·072	0·063	—12·5	1·14	0·46	—59·6
	S/A	0·072	0·058	—19·4	1·09	0·33	—69·8

With regard to humus the following descending order was observed among the types at start: D > A > B > C > E. In a previous publication [Basu and Tagare, 1943] it has been shown that loss of humus is a general rule even under the intensive system of cane growing as practised by the cultivators who generally apply large doses of bulky manures to their cane crop. In the present instance also varying amounts of lossess of humus are noted after the period of experimentation in different types. Thus in the control soils A type shows the greatest loss of 89·9 per cent while B type the least with 41 per cent, the general order of losses among the types being A D > D > E > C > B. The losses of humus with addition of farmyard manure and sulphate of ammonia are also considerable, e.g. 88·3 per cent for A type and 48·9 per cent for B type, the highest and lowest figures of loss in the farmyard manure treatment and 87·2 per cent for A and 32·0 per cent for C for the corresponding figures of sulphate of ammonia treatment. Generally speaking, under all treatments A, D, E have suffered greater losses in humus than the types B or C.

DISCUSSION

The result of this experiment has clearly brought out the inherent differences in the bio-chemical behaviour of the soil types studied in this paper and their differential responses to both organic and inorganic manuring. We propose to discuss briefly here the various physical and chemical factors which are responsible for the above characteristic behaviour of the soil types and to indicate their bearing on the manuring problems of each in a general way.

Micro-biological methods of soil analysis, generally employed to assess soil fertility, fall under two main heads: (1) Direct methods in which the numbers and types of micro-organisms occurring in the soil are determined, (2) Indirect methods where the products of micro-biological activities in the soil which are of immediate utility to the development of plants are determined, such as by measuring the nitrate or ammonia formation in soils. We shall now examine the result of our experiment from the above two points of view.

The average bacterial numbers in the untreated soils show the following descending order: E > A > C > D > B. It will be interesting to see that this order follows more or less the order of the total base saturation capacities of these types (Table II). Similar observations, namely, that bacterial numbers vary accordig to the colloidal surfaces of soils, have been made by others. [Waksman, 1931]. The lower pH values of A and E types might have been also responsible for higher bacterial activities in these types. As can be expected, the

higher C/N ratios in the types A, C, D and E show in a general way higher bacterial numbers when compared to the number in B type which exhibits the lowest ratio. The inferior morphological features of C type are, however, not reflected in the bacterial numbers of this soil.

Addition of farmyard manure has encouraged bacterial activities in certain types (C, D and B) more than in others (A or E). This increase in bacterial number by addition of manure has been observed by various workers [Waksman, 1931] and has been attributed to either or all of the factors—(1) Phyisical improvement in the soil (2) Supply of energy material, (3) Supply of available nutrients, and (4) Actual incorporation of bacteria. The greatest response of C type may be accounted for by either of the factors (1) or (3) while in B the improvement is likely to be due to the factor (2) primarily. It is difficult to explain why D type has shown such a good response although in the case of A or E it must be assumed that optimum conditions already existed for proper development of bacteria and hence the responses were the least with them. The bacterial response in soils to the application of ammonium sulphate is known to occur when there is either lack of available nitrogen in the soils or high soil reaction, as sulphate application may be responsible for temporary lowering of pH. In all these soils, however, the actual responses have been only to a small extent and that is due probably to the fact that they are fairly well-supplied with nitrogen, at least for the purpose of bacterial growth. Slight temporary lowering in pH may be responsible for increased bacterial numbers in the case of B and C types.

Waksman [1931] has suggested three methods of determining the nitrifying capacities of soils: (i) nitrification of soils' own nitrogen, (ii) nitrification of ammonium sulphate, and (iii) nitrification of organic nitrogenous materials. He has recommended incubation of the soil at a moisture content of 50 to 60 per cent of the saturation value and at a temperature of 25°-30°C. for a period of 30 days. It will be evident from Fig. 2 that fixing up of such an arbitrary period of 30 days is not possible in the case of different soil types in view of the fact that the time of maximum nitrification in soils varies with the nature of the material used for studying nitrification as well as on the soil types.

It will be evident from Table VI that the maximum nitrification occurs from 40 to 120 days after the treatments are given in different soil types. In the case of sulphate of ammonia the per cent nitrification figures are sometimes more than double than those after 30 days after start. In the case of farmyard manure, of course, a period of 30 days is definitely insufficient as only a trace of nitrate is observed over the control in most cases. A period of 60 to 110 days is required to arrive at the maximum nitrifying powers of these soils. It will be, therefore, clear from the above data that for determining the nitrifying power of a soil it is

TABLE VI

Nitrification in different soil types

Soil types	With sulphate of ammonia				
	A	B	C	D	E
Maximum nitrate nitrogen mg. per cent	14·7	17·6	11·0	13·6	22·1
No. of days for maximum nitrification	120	40	100	120	60
Nitrate nitrogen after 30 days mg. per cent	5·2	7·5	8·0	8·6	12·3
	With farmyard manure				
Maximum nitrate nitrogen mg. per cent	13·4	—0·4	0·4	13·3	1·5
No. of days for maximum nitrification	60	*Nil.*	*Nil.*	70	110
Nitrate nitrogen after 30 days mg. per cent	—0·3	—1·0	—0·1	2·2	0·3

extremely risky to fix up any arbitrary period of incubation (say, 30, 60 or 90 days) without ascertaining the optimum period for a particular soil type by conducting some preliminary experiments. Further, as plants utilize nitrate slowly and gradually with their growth it stands to reason that measurement of nitrate contents of soil at a particular time (say at the peak period or after 30 days) after the application of fertilizers can not provide us with a true index of their efficiencies with reference to a growing plant. The process is a dynamic one and levels of available nitrogen (over a fairly long period) by averaging the contents at different times (closer the period of determination the better) to assess the intrinsic fertilizing value of any treatment. Thus taking the percentage increase over the control of the average figures (of 12 occasions) of nitrate in the treated soils we find that the order of response with sulphate of ammonia is as under: C>E>D>B>A. With farmyard manure we find that only D and E types are responding well (D being >E) while A, C and B show depressing effects. The depressing effect of farmyard manure to B type of soil has already been discussed in more detail in a previous publication [Basu and Vanikar, 1942].

Finally as the fertility of soils depends largely on the availability of nitrogen (provided the soils are well provided with other plant food ingredients) the order of fertility (of untreated soils) of different soil types is A >B, D > E > C taking the average levels of nitrate in these soils during the period of this experimentation If either ammonia or mineral nitrogen levels are taken for judging the fertility they are A, B > D > C > E > or A > B>D > E > C respectively. The agreements are fairly good taking the different indices of availability and we may say that the soil types A, B and D are more fertile than the types E or C. This has been more or less borne out by our experiments at the sub-stations conducted on some of these types. Similar relationship between crop yield and nitrate accumulation in soils has been observed by others [Waksman, 1931].

Summary

Pot-culture experiment with five soil types—named A to E belonging to the broad group of black cotton soil of India has been described in which the biochemical changes have been carefully followed after the additions of farmyard manure and sulphate of ammonia respectively. The moisture level has been maintained at half the maximum moisture holding capacity (which approximates to 2/3 field saturation capacity) by making it up by addition of water at regular intervals. The results obtained are set forth briefly below:

(1) From the point of view of average bacterial numbers the soil types can be arranged in the following descending order: E > A>C>D > B. This is also found to be more or less the descending order of the total base saturation capacities of these soils.

(2) From the average figures of mineral nitrogen (i.e. nitrate plus ammonia) in these soil types the following descending order is obtained: A >B> D > E > C. Very similar order is also shown by the yield data of sugar grown on some of these soil types at sub-stations.

(3) From the average nitrate levels in the soils with the application of sulphate of ammonia it is observed that the order in which the various types respond to this fertilizer is C > E>D>B> A.

(4) From a similar consideration in the case of farmyard manure it is found that a good response is shown by D type, while E type gives only a slight response. The rest of the types studied in this experiment do not show any response to this manure.

(5) Under the conditions of this experiment all soil types show losses of nitrogen in varying extent excepting the untreated soil from A type. E type has lost much less nitrogen than the rest of the types. Losses of humus have also been considerable in all cases. A, D and E types showing much greater values than either B or C types.

(6) The drawback in fixing up an arbitrary period of incubation in the determination of nitrifying powers of different soil types has been pointed out and more reliable method of assessing the fertilizer requirement of a soil type indicated.

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PRELIMINARY STUDY ON THE INFLUENCE OF VARIETY, MANURES AND IRRIGATION ON THE COMPOSITION AND QUALITY OF BARLEY

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Barley (*Hordeum vulgare*, Linn) occupies nearly six-and-a-half million acres in India and the annual outturn is estimated at about two and a one-third million tons of grain. In regard to acreage, India is the second largest barley growing country of the world. It is one of the principal crops of the United Provinces where nearly two-thirds of the above acreage, viz. about four million acres are annually put under this crop. It is also interesting to note that this province produces more barley than the whole of Canada and nearly half as much as the total of the United States of America. Much of the importance of barley lies in the circumstance that if well suited for malting, it commands a price far higher than it could obtain if sold for food, the difference being sometimes as much as 50 per cent or even in special cases 100 per cent [Russell, 1937].

In comparison with other barley producing countries, very little systematic effort has been made in India, and specially in the United Provinces, to scientifically assess the brewing quality of the locally grown barley as influenced by the varietal, soil, climatic, manurial or other factors. Under a grant from the Imperial Council of Agricultural Research, India, some work was, however, carried out in which the malting quality of a few selected strains of barley collected from the United Provinces was investigated. In the present paper results of an investigation of a preliminary nature have been described which although not very exhaustive, may nevertheless prove to be of considerable economic value to those who like to grow barley for brewing purposes.

Literature

Much has already been done in other countries to elucidate some of the important aspects of quality in barley and a brief summary of the more striking conclusions so far arrival at is given below. In regard to the quality of grains as affected by manuring a large number of experiments have shown that nitrogenous manures increase the nitrogen content of the grains. Work done at Rothamsted during 1922-32 [Annual reports 1930, 1931, 1932] has clearly demonstrated that increased amounts of nitrogenous fertilizers may increase the nitrogen content of barley to such an extent as to be injurious to the brewing quality of the grains; since nitrogen rich barley is considered useless for malting purposes. Earlier work at the same station [Annual report 1929] had demonstrated that one cwt. of sulphate of ammonia per acre might be considered to be the optimum dose for this purpose. Higher doses were found to add little to yield and tended to spoil the quality. Similar results were obtained by Richardson and Gurney [1933] in South Australia who found that dressings of sulphate of ammonia in excess of 56 lb. per acre considerably increased the nitrogen content of the grains which reacted very adversely on their malting quality. Seischab [1930, 1933] reported that excessive nitrogenous manuring increased the grain size and the

weight per 1000 grains; and Prosting [1936] described the effect of an excess of nitrogen supply on the composition of barley grains. The latter worker found that the amide nitrogen content of grains was raised in consequence of increased nitrogen supply and with a high level of nitrogen in the soil and inverse relationship was set up between the sizes of the aleurone cells and starch grains. Opitz [1940] reported that application of nitrogen increased the yield of barley and top dressings at early stages of growth were found to be significantly effective in increasing the grain yields. Phosphates in conjunction with nitrogen were found to be effective in raising the yield of barley grains in Germany specially with good water supply as evinced by the recent experiments of Schimtt and Schineis [1940].

Dreyspring, Kurth and Heinrich [1931] and Krugel, Dreyspring and Kurth [1933] observed that application of soluble phosphatic fertilizers to barley increased the grain size, weight per 1000 grains, starch content and yield of extract; whereas, the nitrogen content was decreased. Burgeoin and Guyon [1933] obtained increased dry matter production and increased phosphoric acid intake as a result of heavy phosphatic manuring. Phosphates have been found at times to increase the protein content of grains as reported by Schimtt and Schineis [1940] and Richards and Templeman [1936]. Opitz, Rothsack and Morganroth [1937] who grew barley in sandy soil normally deficient in nutrients and to which a basic supply of nitrogen was added, on the other hand, found that an increase in the phosphate supply of the soil resulted in an increase in the phosphoric acid content of the grains and a marked decrease in both nitrogen and potash contents. Mukerji and Agarwal [1943] similarly reported a decrease in the nitrogen content of the grains of barley (C 251) by increasing the supply of phosphoric acid in the soil.

Recent work on the time of application of fertilizers has encouraged the belief that early dressings increase the yield only affecting a little the crude protein content; whereas, late application at the time of flowering considerably increase the protein content of the grains [Nehring and Schramm, 1940; Opitz, 1940].

The Institute of Brewing, London, during 1922-32 carried out extensive investigations, in co-operation with the Rothamsted Experimental Station, on the effect of soil, season, manuring and variety on the quality of barley. The results of this excellent research have been published by Russell and Bishop [1932] and a general summary of their conclusions may be stated as follows. The chief factors in determining the quality were found to be the soil and the weather. The date of sowing had marked effect, rate of seed and spacing little. Widening the rows was found to increase the nitrogen content. It was also found that sowing late lowered the yield but increased the nitrogen content. Draught was found usually to raise the nitrogen content.

One of the most remarkable advance made as a result of the above investigation was the work of Bishop [1936] who gave a new method of the valuation of malting and brewing quality of barley based on one thousand corn weight, nitrogen content and the dry matter of the grains. Hand valuation by maltsters was considered uncertain or even misleading. As a result of statistical scrutiny of a large body of data Bishop [1930] found that the brewers' extract from barley, in case they germinate well, was inversely related to the nitrogen content of the grain and directly to the corn weight. The equation suggested for predicting the value of extract was as follows:

Extract$=$110. 1-11. $2N+0.$ 18 G, where N is per cent total nitrogen and G the weight of one thousand grains in grams on dry basis.

Bishop and Day [1933] subsequently modified the equation for the extract to $E=$A-10. 5 $N+0.$ 20 G, where A is a constant depending upon the variety of barely. Excellent agreement was claimed between the experimental and predicted values for the extract with the help of the above equation. An almost identical equation was proposed by Petit [1933] for French barleys and according to him an error of 1-2 per cent only between the predicted and actual values was obtained.

Experimental

Samples of barley of different varieties grown during 1940-41 under identical soil and other environmental conditions on the Government Research Farm, Cawnpore, in a varietal trial conducted by the Economic Botanist (Cotton and *Rabi* Cereals) to Government, U.P., were secured and analysed. The nitrogen content was estimated in the usual manner by the Kjeldahl method and the one thousand corn weight was determined by weighing carefully four lots of counted one hundred grains from each of the samples. The extract in brewers' lb. per qr. was calculated by using the Bishop and Day's [1933] formula. It has been assumed in the present study that all the samples of barley examined will germinate

well. This was verified in a number of cases by qualitative germination tests as well. The value of the constant A in the equation was kept at 104—a value found for Indian barleys by the Institute of Brewing, London (private communication), although there are indications that Indian barleys demand a value as high as 110-112. The calculated quantity of extract obtained may not, therefore, be regarded as absolute but the results are, nevertheless, comparable amongst themselves. The data are presented in Table I.

TABLE I

Variety as affecting the quality of barley grains, 1940-41

(Government Research Farm, Cawnpore)

Serial No.	Variety	Nitrogen per cent	1000 corn wt. gm.	Extract Brewers' lb. per qr.
1	IP 21	1·30	48·75	100·1
2	C 74	1·36	51·83	100·3
3	C 84	1·38	56·90	100·9
4	C 85	1·35	51·06	100·0
5	C 86	1·39	49·38	99·3
6	C 94	1·37	58·02	101·2
7	C 95	1·47	60·03	100·6
8	C 251	1·38	52·01	99·9
9	C 285	1·41	54·16	100·0
10	C 259	1·39	54·76	100·6
	S. E.	±0·0365	±0·8056	..

It will be observed from Table I that IP 21 gives significantly lower nitrogen than the rest and that C 95 contains the highest amount of this ingredient. The one thousand corn weight is lowest for IP 21 and highest for C 95. This varietal difference was, however, not found to be consistent in subsequent studies. In all the varieties examined by us it may be noted that nitrogen ranges from 1·30-1·47 per cent and the one thousand corn weight from 48·75-60·03 gm. The lower nitrogen content and higher one thousand corn weight of Indian barleys as compared with English or Californian barleys, as reported by Bishop [1933], may give to the former greater value for malting purposes. The varietal differences, however, do not show much marked effect on the value for the extract.

With a view to discover differences in the varieties of barley when used as a feeding stuff, the grains were also examined for the important minerals in the ash by the ordinary methods. Table II contains the results of this analysis.

TABLE II

Chemical analysis of different varieties of barley grown in U. P. under the same manurial, cultural and soil conditions, 1940-41

(Per cent dry basis)

Serial No.	Description	Total organic matter	Total nitrogen	Crude protein	Total ash	CaO	P_2O_5	K_2O
1	IP 21	96·827	1·30	8·12	3·173	0·1040	0·6002	0·7348
2	C 74	97·640	1·36	8·50	2·360	0·1044	0·5109	0·6327
3	C 84	97·284	1·38	8·62	2·716	0·1099	0·6255	0·7326
4	C 85	97·526	1·35	8·45	2·474	0·1013	0·5359	0·6667
5	C 86	97·518	1·39	8·70	2·482	0·1337	0·6337	0·8249
6	C 94	97·590	1·37	8·55	2·410	0·1122	0·7134	0·8478
7	C 95	97·532	1·47	9·20	2·468	0·0859	0·6785	0·8210
8	C 251	97·590	1·38	8·62	2·410	0·1043	0·6365	0·8210
9	C 255	97·479	1·41	8·81	2·521	0·1116	0·5074	0·6616
10	C 259	97·321	1·39	8·70	2·679	0·1210	0·6582	0·8960

It may be seen that there is not much variation in the different ash constituents of the varieties examined. Lime is more or less constant at 0·104-0·121; except C 95 which gave a lower figure and C 86 which gave a higher one. In regard to phosphoric acid it seems that C 74, C 85 and C 255 may be considered poorer in this ingredient having 0·507-0·536 per cent P_2O_5; IP 21, C 84, C 86, C 251 and C 259 may be considered to have an average content with a range of 0·600-0·658 per cent and C 94 and C 95 may be regarded as richer with a range of 0·679-0·713. Potash similarly varies from 0·633 to 0·896 per cent.

Effect of manurial differences

As will be clear from the literature reviewed above manurial treatment considerably alters the composition of barley grains and as such is one of the chief factors in determining the quality both for brewing and feeding purposes. It has also been shown that nitrogen and phosphoric acid in the manure are the two chief constituents which determine both the yield and quality of barley grains. Samples of grains of barley (C 251) from a manurial trial conducted by the Economic Botanist (Cotton, Paddy and *Rabi* Cereals) to Government U.P. on the Government Cotton Farm, Raya (Muttra), during 1940-41 were collected and analysed.

Table III contains the results of the chemical analysis of composite samples of the grains from the different treatments. There were four levels of nitrogen (viz. 0, 20, 40 and 60 lb. per acre) in the form of ammonium sulphate and three levels of phosphoric acid (viz. 0, 15 and 30 lb. per acre) as superphosphate in the trial.

Some very interesting conclusions emerge out of this investigation which throw considerable light on the nutrition of barley plant. These conclusions are briefly described below:

(*a*) *Proteins*. Increaisng the quantity of nitrogen in the fertilizer increases the nitrogen assimilation of barley and consequently the protein content is also increased. Phosphoric acid has an inverse action and increased level of phosphates has lowered the protein content. Plots receiving no nitrogen and no phosphoric acid gave grains with a protein content of 8·93 per cent; whereas, adding 30 lb. P_2O_5 per acre lowered this to 7·24 per cent. These results are in agreement with those obtained by Opitz, Rothsach and Morganroth [1937]; Dreyspring, Kurth and Heinrich [1931]; and Krugel, Dreyspring and Kurth [1933]. During 1941-42, however, when these results were again verified at Raya it was observed that higher doses of nitrogenous fertilizers increased the nitrogen content of barley grains but phosphatic manures showed an erratic effect (Table V). It seems, therefore, that nitrogenous fertilizers have in general an effect of increasing the uptake of nitrogen in the grains but phosphatic fertilizers may or may not have any effect. Almost similar conclusions were arrived at in the Rothamsted Field Experiments on barley during 1852-1937 as described by Russell and Watson [1939].

(*b*) *Phosphoric acid.* This constituent increases markedly with an increase in the phosphoric acid content of the manure, as one would expect, and slightly so by an increase in the nitrogen supply.

(*c*) *Lime.* Lime is inversely related to phosphoric acid. With an increase in the nitrogen content, too, there is a slight decrease in lime content of grains, but at higher levels of phosphoric acid it is better maintained by increasing the dose of nitrogen.

In regard to the yield of barley as a result of the above manurial treatments it may be mentioned that the response to nitrogen was significant at 40 lb. and 60 lb. nitrogen per acre only. The increase in yield over the control by 20 lb. nitrogen per acre was not significant. Moreover, there was no difference between the applications of 40 lb. and 60 lb. nitrogen per acre. The former dose, therefore, seems to be the best. Phosphates had no influence on yield of grain and no interaction was observed. The summary of these results, obtained through the courtesy of the Economic Botanist (Cotton, Paddy and *Rabi* Cereals), is given in Table IV.

In general it may be stated that the application of phosphatic manures to barley, under the conditions of the above experiment, seems uneconomical as it does not add to the yield of grains and at the same time does not improve the quality to an extent commensurate with the cost of fertilizer. The use of nitrogenous manures may be considered useful provided small doses are added which do not raise the nitrogen content to the extent so as to spoil the malting quality, although a higher protein content may be desirable for feeding purposes. 40 lb. nitrogen per acre increases the yield without injuring the quality and the protein content also remains fairly high.

The above conclusions were verified again during the season 1941-42 and the brewers' extract obtainable was calculated by applying the formula proposed by Bishop and Day

TABLE III

Effect of different levels of nitrogen and phosphoric acid in the manure on the composition of barley (C 251), 1940-41

(Per cent dry basis)

Serial No.	Description (lb. per acre)	Total organic matter	Crude protein	Crude fat	Crude fibre	Total Carbohy-drates	Total Ash	CaO	P_2O_5	K_2O
1	0 lb. N; 0 lb. P_2O_5	97·521	8·93	2·523	5·146	86·068	2·479	0·1288	0·663	0·780
2	20 lb. N; 0 lb. P_2O_5	97·500	7·20	2·360	4·514	87·940	2·500	0·1092	0·676	0·760
3	40 lb. N; 0 lb. P_2O_5	97·491	9·12	2·130	4·535	86·241	2·509	0·1052	0·671	0·741
4	60 lb. N; 0 lb. P_2O_5	97·420	9·12	2·221	4·457	86·079	2·580	0·1140	0·674	0·632
5	no N; 15 lb. P_2O_5	97·409	7·82	2·192	4·938	88·408	2·591	0·1090	0·673	0·798
6	20 lb. N; 15 lb. P_2O_5	97·489	8·46	2·257	4·893	86·772	2·511	0·1072	0·665	0·752
7	40 lb. N; 15 lb. P_2O_5	97·445	7·80	2·404	5·012	87·241	2·255	0·0996	0·716	0·740
8	60 lb. N; 15 lb. P_2O_5	97·440	8·72	2·154	4·674	86·566	2·560	0·0974	0·748	0·683
9	0 lb. N; 30 lb. P_2O_5	97·404	7·24	2·571	5·189	87·593	2·596	0·0853	0·710	0·641
10	20 lb. N; 30 lb. P_2O_5	97·481	7·99	2·255	4·939	87·236	2·519	0·0851	0·756	0·582
11	40 lb. N; 30 lb. P_2O_5	97·622	8·34	2·224	4·789	87·058	2·378	0·0824	0·760	0·780
12	60 lb. N; 30 lb. P_2O_5	97·246	8·50	2·564	4·729	86·882	2·754	0·0891	0·848	0·650

TABLE IV

Yield of barley grain in lb. per acre, 1940-41

Particulars	60 lb. N per acre	40 lb. N per acre	20 lb. N per acre	No nitrogen	Mean differences	Significant
Yield in lb. per acre	3028	3023	2880	2778	2927	191·3
Percentage over mean	103·5	103·3	98·4	94·9	100	6·54

[1933]. Samples of barley grains collected from two manurial trials one at Belatal (Jhansi) and the other at Raya (Muttra) were analysed. There were 12 treatments consisting of four doses of nitrogen (0, 20, 40 and 60 lb. per acre) at three levels of phosphoric acid (0, 7½, and 15 lb. per acre) in the trial. The data obtained with respect to malting quality are tabulated in Table V.

TABLE V

Manurial trials on barley (C 251) with different levels of nitrogen and phosphates, 1941-42

Serial No.	Treatment in lb. per acre	Belatal: Nitrogen on dry basis (per cent)	Belatal: Wt. per 1000 grains (dry basis) (gm.)	Belatal: Extract (Cal) (lb. per qr.)	Raya: Nitrogen on dry basis (per cent)	Raya: Wt. per 1000 grains (dry basis) (gm.)	Raya: Extract (Cal) (lb. per qr.)
1	N 0; P_2O_5 0 . .	1·697	41·58	94·50	1·414	43·24	97·80
2	N 20; P_2O_5 0 . .	1·771	42·25	93·85	1·530	45·20	96·98
3	N 40; P_2O_5 0 . .	1·945	41·53	91·88	1·633	43·59	95·57
4	N 60; P_2O_5 0 . .	1·988	40·12	91·15	1·828	43·38	93·48
5	N 0; P_2O_5 7½ . .	1·843	41·42	92·93	1·450	45·74	92·92
6	N 20; P_2O_5 7½ . .	1·832	41·43	93·05	1·681	42·28	94·81
7	N 40; P_2O_5 7½ . .	1·878	39·22	92·13	1·585	42·22	95·80
8	N 60; P_2O_5 7½ . .	1·913	40·39	92·00	1·840	42·95	93·27
9	N 0; P_2O_5 15 . .	1·684	40·01	94·32	1·419	44·89	98·08
10	N 20; P_2O_5 15 . .	1·845	35·44	91·72	1·504	44·85	97·18
11	N 40; P_2O_2 15 . .	1·829	39·74	92·74	1·588	44·02	96·13
12	N 60; P_2O_5 15 . .	1·753	43·42	94·28	1·897	44·63	93·01

Nitrogenous dressings, as one would expect, considerably increase the nitrogen content of grains although there seems to be not much consistent change in the size of the grain. Hence the value of the extract decreases slightly by increasing the nitrogen in the manure. Phosphates seem to have an erratic effect. Higher doses of nitrogen may, therefore, not be considered advisable for securing better quality of barley.

Effect of irrigation

Samples of barley from three varietal trials conducted under irrigated and unirrigated conditions during the season 1941-42 from three places in the province, viz. Government Cotton Research Farm, Raya (Muttra), Government Research Farm, Cawnpore, and Government Agricultural Farm, Belatal (Jhansi), were received from the Economic Botanist (Cotton, Paddy and *Rabi* Cereals) to Government, U.P., Cawnpore, for analysis with a view to assess their brewing quality. Samples of 12 varieties each from irrigated and unirrigated conditions were received both from Cawnpore and Raya and of 10 varieties each from both the treatments from Belatal.

The analytical data obtained for both the irrigated and unirrigated samples from the three places are presented in Tables VI, VII and VIII.

TABLE VI

Varietal trial under irrigated and unirrigated conditions, 1941-42

(Government Cotton Farm, Raya)

Serial No.	Variety	Irrigated			Unirrigated		
		Nitrogen on dry basis (per cent)	Wt. per 1000 grains (dry basis) (gm.)	Extract (Cal) (lb. per qr.)	Nitrogen on dry basis (per cent)	Wt. per 1000 grains (dry basis) (gm.)	Extract (Cal) (lb. per qr.)
1	34-84	1·471	47·85	98·12	1·950	50·01	93·63
2	34-85	1·328	46·24	99·30	1·683	47·24	95·78
3	34-86	1·495	42·90	96·88	1·830	45·52	93·89
4	34-74	1·512	47·29	97·58	1·901	46·92	93·42
5	C 251	1·438	44·77	97·86	1·917	43·03	92·48
6	IP 21	1·570	45·61	96·64	2·089	41·73	90·41
7	35-50	1·503	47·89	97·80	2·071	49·58	92·17
8	35-44	1·450	48·53	98·68	1·975	45·31	92·32
9	35-63	1·524	49·56	97·91	1·833	47·64	94·28
10	35-33	1·606	49·68	97·07	2·145	48·47	91·17
11	35-37	1·487	47·66	97·92	2·129	46·52	90·95
12	Local	1·657	51·98	97·00	1·953	51·34	93·76

TABLE VII

Varietal trial under irrigated and unirrigated conditions, 1941-42

(Government Research Farm, Cawnpore)

Serial No.	Variety	Irrigated			Unirrigated		
		Nitrogen on dry basis (per cent)	Wt. per 1000 grains (dry basis) (gm).	Extract (Cal) (lb. per qr.)	Nitrogen on dry basis (per cent)	Wt. per 1000 grains (dry basis) (gm.)	Extract (Cal) (lb. per qr.)
1	35-23	1·585	48·34	97·03	2·512	47·99	87·22
2	35-33	1·560	39·97	95·61	2·345	46·14	88·61
3	35-50	1·741	41·11	93·94	2·381	51·29	89·36
4	35-44	2·399	40·15	96·85	2·436	47·67	87·96
5	35-24	2·369	47·19	98·56	2·593	50·69	86·91
6	35-17	1·473	43·21	97·18	2·313	46·39	88·99
7	35-45	2·468	38·02	85·69	2·673	45·56	86·05
8	34-84	1·742	45·86	94·88	2·503	55·08	88·73
9	34-85	1·603	43·84	95·94	2·426	46·29	87·79
10	34-86	1·586	46·79	96·71	2·239	44·76	89.43
11	C 251	1·479	43·09	97·09	2·433	42·25	86·89
12	IP 21	1·822	40·97	93·06	2·403	42·37	87·24

TABLE VIII

Varietal trial under irrigated and unirrigated conditions, 1941-42

(Government Agricultural Farm, Belatal)

Serial No.	Variety	Irrigated			Unirrigated		
		Nitrogen on dry basis (per cent)	Wt. per 1000 grains (dry basis) (gm.)	Extract (Cal) (lb. per qr.)	Nitrogen on dry basis (per cent)	Wt. per 1000 grains (dry basis) (gm.)	Extract (Cal) (lb. per qr.)
1	35-11	1·963	45·69	92·53	2·370	42·47	87·62
2	35-40	1·771	50·23	95·45	2·510	44·88	86·60
3	35-50	1·983	47·95	92·77	2·572	47·46	85·49
4	35-52	2·133	49·70	91·52	2·490	50·19	87·89
5	35-56	2·042	47·14	91·99	2·541	42·51	85·82
6	34-84	1·790	50·45	95·29	2·369	48·87	88·90
7	34-86	1·712	45·84	95·19	2·480	43·63	86·69
8	34-94	1·904	52·17	94·44	2·390	48·85	88·67
9	C 251	2·071	55·67	93·39	2·392	42·09	88·32
10	Local	1·760	43·42	94·20	2·452	41·99	86·57

It may be seen from the above tables that although variety seems to have effect on the nitrogen content and consequently on extract this is decidedly less significant than the effect due to irrigation. Barleys grown under irrigated conditions have in every case given lower nitrogen and higher extract than those grown under unirrigated conditions. The effect due to varieties has not been consistent from place to place but the effect of irrigation has been found to be highly consistent. It seems that although barley may take up the same amount of nitrogen from the soil the greater yield of grain under irrigated condition results in greater carbo-hydrate production so that a lower nitrogen percentage results. Similar results were obtained in America by Greaves and Carter [1923] for wheat, oats and barley. The decrease in the nitrogen content as a result of irrigation has been considerable and this modifies to a great extent the brewing quality of barley. It seems that unirrigated barley will be much inferior, if not altogether useless, for malting purposes. The high protein content may confer on this type of barley, however, superior feeding qualities.

Effect of locality

In order to study the effect of locality on the quality of barley, data for the common varieties of barley grown under irrigated conditions have been selected out from the above tables and presented in Table IX for the sake of comparison.

TABLE IX

Effect of variety and locality on quality of irrigated barley

Serial No.	Variety	Raya		Cawnpore		Belatal	
		N (per cent)	Ext. (lb. per qr.)	N (per cent)	Ext. (lb. per qr.)	N (per cent)	Ext. (lb. per qr.)
1	34-84	1·471	98·12	1·742	94·88	1·790	95·29
2	34-86	1·495	96·88	1·586	96·71	1·712	95·19
3	35-50	1·503	97·80	1·741	93·94	1·983	92·77
4	C 251	1·438	97·86	1·479	97·09	2·071	93·39
5	IP 21	1·570	96·64	1·822	93·03	..	..

It is apparent that in every case barley grown at Raya contains lower nitrogen than that grown at Cawnpore and this in turn contains less nitrogen than that grown at Belatal. The figures for extract are in inverse order. These figures, although may not hold for every season, yet clearly show that the varietal differences are quite subordinate to differences due to soil, climate and irrigation as far as the quality of barley is concerned. Russell [1937] similarly mentions that the soil and climatic conditions play a very important part in deciding the quality in barley.

Summary

(1) The varietal differences on the malting and feeding quality of barley have been investigated with all the common varieties of United Provinces.

(2) The effect of different levels of nitrogen and phosphoric acid as fertilizers on the quality of barley grains for barley (C 251) has been investigated and discussed.

(3) It has been found that barley produced under unirrigated conditions will be much inferior, if not altogether useless, for malting purposes due to its higher nitrogen content. The high protein content may confer on this type of barley, however, superior feeding qualities.

(4) Evidence has been adduced to show that varietal differences are quite subordinate to differences due to soil climatic and environmental factors as far as the quality of barley is concerned.

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STUDIES ON INDIAN RED SOILS

VIII. STUDIES ON THE PHYSICO-CHEMICAL AND MINERALOGICAL PROPERTIES OF SOME INDIAN RED AND LATERITIC SOILS

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(With two text-figures)

Red soils occur extensively throughout India, in the Madras Presidency, in Hyderabad, in Central Provinces, in Bihar, in Orissa and in parts of Bengal and Assam. The compositions of these soils vary widely. The soils are generally poor in nitrogen, phosphorus and humus, while the alkali content is fair. Some patches are comparatively rich in potash, iron, lime and magnesia. In comparison with the *regur* these soils are poorer in lime, potash, iron oxide and are also uniformly low in phosphorus content.

Laterite is a formation peculiar to India and some other tropical countries with intermittently moist climate. It is a compact vesicular rock composed essentially of a mixture of the hydrated oxides of aluminium and iron with a small amount of MnO_2., TiO_2,, etc. The laterite is especially well-developed on the summits of plateaux and hills of the Deccan, Central India, Central Provinces, Rajmahal, the Eastern Ghats of Orissa, South Bombay, Malabar and parts of Assam. Laterite, which scarcely occurs on situations below 2,000 ft. above sea-level, is known as 'high-level laterite', the rocks of which are characterized by massive homogeneous grains and are of uniform composition. The above type of laterite is differentiated from what is known as the 'low-level laterite' which occurs on the coastal low lands, on both sides of the Peninsula. Low-level laterite is also sometimes known as 'detrital', 'reconsolidated' or 'secondary laterite' and has been formed from the products of mechanical disintegration of high-level laterite [Fox, 1923]. Fox [1936] points out that the chemical analyses of the so-called laterite soils of India, show clearly that Buchanan's original laterite consists mainly of what we should now call lithomargic laterite and even in part lateritic lithomarge.

A critical account of the origin and nature of laterites and lateritic soils of India has been given by Raychaudhuri [1937], who, in a later publication [1941], has described the morphological features of a number of profiles of red soils of India. Raychaudhuri and Nandymazumdar [1940] have shown that the buffer curves of profile samples of Indian red soils indicate a more or less definite inflexion at pH 9·8 and frequently a second inflexion at pH 2·9 or at pH 4·6. In a recent paper Raychaudhuri and Mukherjee [1942] have reported the results of their studies on the mineralogical composition of some Indian red and lateritic soils and on the basis of the percentage of the mineralogical constituents in the profile samples, have divided the soil profiles tentatively into five groups, viz. (1) zircon preponderant, (2) hornblende preponderant, (3) rutile preponderant, (4) epidote preponderant, and (5) tourmaline preponderant. When these investigations were being carried out, profile samples of red soils of Bengal and of certain tracts in Southern India were not available for work. Typical profile samples have been subsequently collected by one of the authors (Raychaudhuri) and in the present paper, in continuation of the previous works, the physico-chemical properties and mineralogical compositions of samples of seven red soil profiles of Bengal and of Southern India have been examined.

Experimental

The following properties of the profile samples have been described in order:

(A) Mechanical compositions.

(B) Chemical compositions.

(C) Mineralogical compositions of the sand fractions.

(D) Examination of buffer capacities of profile samples.

(E) Cataphoretic speeds of clay particles in cm./sec. per volt/cm. at different concentrations of sodium chloride solutions.

The mechanical analyses of the soils were carried out by following essentially the procedure suggested by Robinson [1933]. Clay fractions for chemical analyses were separated from the soil by the usual sedimentation method and purified by ordinary dialysis and subsequently by electro-dialysis. The separation and identification of minerals in the heavy fraction of fine sand (Sp. gr. 2·9) were carried out as described

by Milner [1932]. Buffer capacities were determined by Schofield's method [1933]. The cataphoretic speeds were determined by the procedure of Freundlich and Abramson [1927, 1928].

Results and discussions

A. *Mechanical compositions*

The results of mechanical composition (Table I) show that the percentage of clay fraction is fairly high in all soils except the Tellicherry profile samples. Also, in all cases except Tellicherry the percentage clay content shows a maximum value at an intermediate depth of the profiles. In general, the percentages of coarse sand fractions show minimum values at intermediate depths of the profiles.

TABLE I

Mechanical compositions of soil samples (oven- dry basis)

Locality and Profile No.	Soil No. and depth	Moisture per cent	Coarse sand per cent	Fine sand per cent	Silt per cent	Clay per cent
Bogra (A)	156p (0 in.-1 ft.)	2·37	6·99	43·57	24·20	22·00
	157p (1 ft.- 2ft.)	2·39	4·46	30·38	28·00	33·40
	158p (2 ft.-below)	4·08	3·71	28·44	22·20	40·80
	159p (12 ft.-25 ft.)	2·03	5·60	56·30	18·00	16·80
	160p (25 ft.-30 ft.)	1·76	10·57	68·03	9·20	9·60
Midnapore (B)	162p (0 in.-4 in.)	2·93	4·21	45·81	22·40	23·40
	163p (4 in.-3ft. 4 in.)	5·50	1·27	32·40	22·80	37·20
	164p (3ft. 4 in.-below)	5·37	2·76	31·65	23·80	35·80
Jaydebpore (C)	169p (0 in.-3 in.)	3·16	3·09	38·62	24·60	30·40
	170p (3 in.-1 ft.)	4·19	2·72	27·42	27·80	37·00
	171p (1 ft.-2ft. 6 in.)	4·39	2·53	20·13	29·40	43·20
	172p (2 ft. 6 in.-4 ft.)	5·90	3·46	18·65	30·00	41·00
Bangalore (D)	176p (0 in.-3 ft. 6 in.)	1·44	33·17	25·23	9·40	30·60
	177p (3 ft. 6 in.-4 ft. 6 in.)	1·54	32·67	23·43	9·60	32·60
	178p (4 ft. 6 in.-6 ft.)	1·31	29·76	26·74	15·40	26·00
	179p (6 ft.-7 ft.)	1·12	35·96	29·08	14·00	18·80
Tellicherry (E)	190p (0 in.-4 ft.)	3·75	38·97	15·17	30·40	10·20
	191p (4 ft.-4 ft. 9 in.)	2·97	40·42	25·36	14·80	15·80
	192p (4 ft. 9 in.-below)	2·40	40·65	26·18	12·80	17·60
Pasumalai (F)	197p (0 in.-1 ft. 2 in.)	3·54	26·65	25·45	7·80	35·80
	198p (1 ft. 2 in.-4 ft. 3 in.)	5·37	14·54	15·90	7·40	56·00
	199p (4 ft. 3 in.-8 ft.)	9·13	44·41	29·99	10·20	4·00
Bankura (G)	209p (0 in.-5 in.)	12·68	43·23	26·42	10·00	7·40
	210p (5 in.-1 ft. 2 in.)	3·82	42·39	11·91	5·20	31·40
	211p (1 ft. 2 in.-1 ft. 8 in.)	3·83	40·15	12·06	12·40	30·80
	212p (1 ft. 8 in.-4 ft.)	2·71	50·83	8·73	8·20	24·00
	213p (4 ft.-6 ft.)	3·16	56·75	11·51	11·40	14·00

B. *Chemical compositions*

Table II shows that so far as Martin and Doyne's definition of laterite is concerned (1927, 1930, SiO_2/Al_2O_3 of clay fraction $<1{\cdot}33$), none of the soils can be classed as laterites, whilst only soil Nos. 172p, 176p, 179p, 190p, 192p and 209p may be classed as lateritic (SiO_2/Al_2O_3 of clay fraction between 1·33-2·00). It may thus be inferred that the lowermost layer of soil samples from Jaydebpore, the top and bottom layers of Bangalore soils, as also all samples of Tellicherry and the top layer of Bankura profile may be classed as lateritic, whilst all the other soils should be classed as red loams. In general, the percentages of Al_2O_3 are very high in the clay fractions compared to the percentages of Fe_2O_3. This observation is probably explained by the very low percentages of ferromagnesian minerals in the soils (Table III).

TABLE II

Chemical compositions of clay fractions colour-dry basis)

Profile No.	Soil No.	SiO_2 per cent	Al_2O_3 per cent	Fe_2O_3 per cent	SiO_2/Al_2O_3	$SiO_2/Al_2O_3+Fe_2O_3$
A	156p	51·65	30·76	12·68	2·83	2·31
	157p	50·72	33·62	12·20	2·55	2·08
	158p	49·17	33·62	13·22	2·47	2·01
	159p	51·46	33·14	13·61	2·62	2·09
	160p	49·22	33·45	15·20	2·49	1·96
B	162p	53·18	31·01	11·29	2·89	2·36
	163p	52·97	31·47	10·82	2·84	2·34
	164p	52·98	30·43	11·17	2·94	2·41
C	169p	53·03	32·52	11·15	2·76	2·28
	170p	51·88	34·16	11·68	2·56	2·13
	171p	51·78	34·21	10·43	2·56	2·15
	172p	42·60	45·67	11·61	1·57	1·36
D	176p	47·00	47·70	4·89	1·86	1·75
	177p	60·00	29·42	5·76	3·42	3·11
	178p	52·10	38·90	6·69	2·27	2·07
	179p	52·75	45·53	2·62	1·96	1·90
E	190p	44·40	38·86	15·45	1·93	1·50
	191p	43·03	40·96	14·29	1·77	1·47
	192p	43·42	41·65	13·57	1·76	1·47
F	197p	46·66	36·74	10·91	2·14	1·83
	198p	49·41	35·02	14·98	2·38	1·88
	199p	58·34	28·39	11·34	3·47	2·81
G	209p	47·00	40·04	12·86	1·98	1·66
	210p	47·12	29·56	16·97	2·69	2·00
	211p	45·86	33·92	16·83	2·28	1·74
	212p	47·94	30·70	15·70	2·64	2·00
	213p	50·28	29·47	14·80	2·88	2·24

C. *Minerological composition of fine sand fractions*

The percentages of minerals in the soils vary widely (Table III). Soils of Bogra, Midnapore, Jaydebpore, Pasumalai and Bankura are found to be fairly rich in many minerals,

TABLE III

Grams of various minerals in the heavy fraction of the fine sand per 1000 gm. of soil (oven-dry basis)

Profile No.	Soil No.	Iron-oxide minerals	Zircon	Tour-maline	Horn-blende	Chlorite	Kyanite	Biotite	Garnet	Epidote	Stau-rolite	Leuco-xene	Musco-vite	Rutile	Anatase
A	156p	31·7	37·4	4·08	0·84	1·09	1·08	0·76	0·65	2·10	8·01	2·46	0·86	1·27	0·19
	157p	5·1	4·59	0·18	...	0·27	0·94	...	0·14	0·10	0·43	0·66	0·04	0·43	...
	158p	1·91	1·47	0·56	0·06	0·04	0·14	...	0·08	0·10	0·12	0·48	...	...	...
	159p	3·51	2·44	0·14	0·02	0·06	0·16	0·42	0·05	0·89	0·08	0·48	0·06	0·46	0·11
	160p	4·78	8·37	0·15	0·17	0·10	0·55	0·11	...	0·40	0·61	0·84	0·07	0·42	0·04
B	162p	0·36	0·22	0·07	...	...	0·03	...	...	...	0·03	0·07	0·01	0·005	...
	163p	2·92	1·41	0·55	...	0·13	0·18	0·07	0·08	0·08	0·24	0·17	0·02	0·21	...
	164p	1·97	2·89	0·14	...	0·02	0·11	...	0·01	0·01	0·03	0·46	0·01	0·04	0·29
C	169p	4·40	3·05	0·38	...	...	...	...	...	0·03	0·47	0·51	...	0·13	...
	170p	3·33	1·31	0·16	...	0·008	0·04	...	...	0·02	0·08	0·08	...	0·06	...
	171p	2·10	0·31	0·01	...	0·005	0·04	...	...	...	0·10	0·05	...	0·04	0·007
	172p	3·47	0·91	0·17	...	0·02	0·06	...	...	...	0·34	0·29	...	0·23	0·03
D	176p	1·46	0·46	0·009	0·01	0·02	...	0·01	...	...	...	0·005	...	0·42	...
	177p	0·51	0·10	0·001	0·002	...	0·004	0·01	...	...	...	...	...	0·14	...
	178p	0·46	0·06	0·01	...	0·002	0·002	0·01	...	...	...	...	...	0·14	...
	179p	0·69	0·09	...	...	...	0·01	0·01	...	...	...	...	...	0·42	...
E	190p	7·37	0·13	0·11	0·02	0·02	0·52	0·02	...	...	...	...	...	0·12	...
	191p	9·15	0·65	0·12	...	...	0·34	...	...	...	...	...	...	0·12	...
	192p	17·4	0·20	0·27	...	...	0·31	...	...	...	...	...	...	0·06	...
F	197p	25·96	4·98	0·28	0·22	0·12	0·48	...	1·02	...	...	0·31	...	0·75	...
	198p	17·5	2·94	0·17	...	0·10	0·33	...	0·73	...	...	0·20	...	0·47	...
	199p	0·69	0·08	0·005	0·003	0·005	0·009	...	0·04	0·006	...	0·08	...	...	...
G	209p	6·14	0·26	0·02	0·03	0·13	0·03	...	0·03	...	0·27	0·17	...	...	...
	210p	0·90	0·15	0·002	0·003	0·004	...	0·02	...	...	0·04	0·01	...	0·007	...
	211p	0·52	0·04	0·007	...	...	...	0·006	...	...	0·03	0·01	...	0·003	...
	212p	0·34	0·05	0·008	...	0·008	...	0·43	0·004	...	0·009	0·004	...	...	...
	213p	0·13	0·03	...	...	...	0·006	0·15	...	...	0·008	0·02	...	...	...

TABLE IV

Profile No.	Soil No.	M. eq. base uptake per 100 gm. oven-dry soil at different pH					
		1·3	2·9	4·6	7·1	9·8	12·5
A	156p	—13·1	—3·8	—3·1	3·1	11·7	24·1
	157p	—13·3	—3·6	—0·8	4·1	15·9	27·5
	158p	—13·3	—3·4	—0·9	4·1	18·9	32·2
	159p	—16·9	—3·5	—0·8	1·8	10·0	18·1
	160p	—17·9	—3·5	—0·6	1·5	7·6	14·4
B	162p	—13·2	—3·9	—0·9	2·9	11·0	19·8
	163p	—16·1	—3·5	—1·4	3·8	15·9	28·9
	164p	—18·5	—3·3	—2·0	1·6	14·7	27·0
C	169p	—7·7	—3·5	0·1	10·9	23·3	29·5
	170p	—4·5	—0·6	5·5	12·4	23·8	34·4
	171p	—4·8	—0·6	6·2	14·3	26·5	35·5
	172p	—4·0	—0·9	6·5	13·9	24·1	34·4
D	176p	—4·0	—3·5	—2·1	0·0	7·4	16·9
	177p	—17·9	—12·0	—4·6	—2·7	4·3	13·9
	178p	—15·2	—11·4	—6·9	—2·3	3·6	11·0
	179p	—7·7	—2·3	—1·9	1·9	4·2	9·6
E	190p	—8·0	—3·0	0·3	7·4	18·2	31·3
	191p	—8·0	—3·9	—1·9	4·0	16·0	29·2
	192p	—8·1	—3·3	—2·8	0·7	12·0	25·8
F	197p	—22·2	—10·4	—3·4	—2·1	9·2	23·9
	198p	—24·7	—10·2	—2·7	—1·3	12·6	32·1
	199p	—36·4	—13·2	—2·0	—1·1	25·0	44·6
G	209p	—14·3	—5·0	—0·3	0·7	9·3	16·8
	210p	—17·7	—5·3	0·0	2·1	14·0	25·0
	211p	—17·5	—4·7	0·0	1·2	12·6	24·0
	212p	—16·0	—3·8	0·3	1·2	8·4	19·6
	213p	—18·4	—2·8	1·0	2·6	12·4	22·3

D. *Buffer capacities*

With Bogra samples (156p-160p) the buffer capacity is maximum at an intermediate layer (158p). From a comparison of the data in Table V it is evident that the buffer capacities follow the variations in the percentages of clay fractions down the depths of the profiles. The buffer capacities of Tellicherry samples (190p-192p) decrease with depth. The buffer capacities of other profile samples have the following characteristics:

(1) Buffer capacity has a maximum value at an intermediate layer: Jaydebpore, Bankura, Midnapore and Bogra.

(2) Buffer capacity increases as the depth increases: Pasumalai.

(3) Buffer capacity varies irregularly with the depth: Bangalore.

Table V shows the calculated base combining capacities of the silt and clay fractions of the top samples between pH 1·3 and 7·1.

TABLE V

[*Figures expressed in m.eq. per 100 gm. of material (oven-dry basis)*]

Profile No.	Depth	Soil No.	Uptake of base between pH 1·3-7·1	
			By silt fraction	By clay fraction
A	0 in.-1 ft.	156p	2·6	16·1
B	0 in.-1 ft. 10 in.	162p	3·0	16·1
C	0 in.-3 in.	169p	3·4	18·6
D	0 in.-3 ft. 6 in.	176p	3·6	4·0
E	0 in.-4 ft.	190p	5·9	15·4
F	0 in.-1 ft. 2 in.	197p	13·4	24·3
G	0 in.-5 in.	209p	7·2	15·0

The base combining capacities of the silt fractions are fairly low except in the case of Pasumalai (Madras Presidency) soils.

E. *Cataphoretic speeds of clay particles*

Figs. 1 and 2 show the variations in cataphoretic velocity (c.v.) of clay fractions from

TABLE VI

Velocity of clay particles in cm./sec. per volt/cm. at different concentrations of NaCl solutions
(The particles always migrated towards the anode)

Profile No.	Soil No.	Conc. of clay suspension (gm. per 1000 c.c.)	Conc. of sodium chloride solutions in normality				
			0·0000	0·0004	0·0008	0·0016	0·004
A	156p . .	0·197	—10·0	—10·0	—9·0	—8·2	—7·7
	157p . .	0·459	—11·1	—10·6	—10·0	—8·7	—7·8
	158p . .	0·347	—10·9	—10·9	—9·7	—8·6	—7·8
	159p . .	0·229	—11·7	—11·5	—10·2	—9·3	—8·8
	160p . .	0·126	—14·6	—14·3	—13·7	—13·1	—12·5
B	162p . .	0·179	—16·2	—15·6	—13·7	—11·8	—10·2
	163p . .	0·283	—17·4	—15·9	—12·9	—10·9	—9·7
	164p . .	0·318	—18·5	—13·2	—12·5	—11·7	—10·9
C	169p . .	0·370	—31·8	—27·3	—13·5	—10·9	—9·2
	170p . .	0·319	—35·0	—29·2	—14·6	—10·9	—9·4
	171p . .	0·501	—43·8	—35·0	—15·2	—11·1	—9·7
	172p . .	0·393	—36·5	—31·3	—16·8	—10·3	—9·2
D	176p . .	0·426	—17·5	—17·5	—17·2	—17·5	—15·6
	177p . .	0·585	—14·6	—14·6	—14·3	—14·3	—13·5
	178p . .	0·431	—13·9	—13·9	—13·9	—13·5	—13·1
	179p . .	0·324	—13·7	—13·7	—13·3	—11·7	—10·2
E	190p . .	0·456	—20·8	—20·8	—15·1	—12·9	—10·2
	191p . .	0·540	—19·4	—19·0	—12·3	—10·9	—8·9
	192p . .	0·234	—12·0	—11·8	—11·4	—10·4	—9·2
F	197p . .	0·310	—14·6	—14·6	—14·6	—14·1	—13·7
	198p . .	0·411	—13·5	—13·5	—13·3	—12·9	—12·5
	199p . .	0·440	—12·5	—12·1	—11·7	—11·7	—11·8
G	209p . .	0·351	—14·6	—14·6	—12·9	—12·2	—11·2
	210p . .	0·280	—19·4	—19·0	—15·6	—12·9	—11·2
	211p . .	0·314	—15·6	—14·6	—14·6	—12·5	—11·7
	212p . .	0·400	—15·6	—15·3	—13·5	—11·2	—10·2
	213p . .	0·501	—20·8	—19·4	—14·6	—12·9	—10·9

Bogra and Tellicherry respectively. Fig. 1 shows that the c.v. of clay particles of Bogra soils at first decreases only slightly with increasing concentration of sodium chloride, then a little more rapidly and at concentrations above 0·0016N the c.v. remains fairly constant. Fig. 2, on the other hand, shows that in the case of the soils from the first two layers of the Tellicherry profile (190p and 191p), the c.v. at first remains fairly constant, then decreases suddenly to a low value and afterwards the rate of decrease is slow. With the lowermost sample from the Tellicherry profile however, (192p, 4 ft. 9 in.—below), rate of c.v. is all along small. Graphical representations of the variations of c.v. observed with increasing concentrations with all the profile samples have not been given; it may however be mentioned that the variations of the c.v. are comparatively

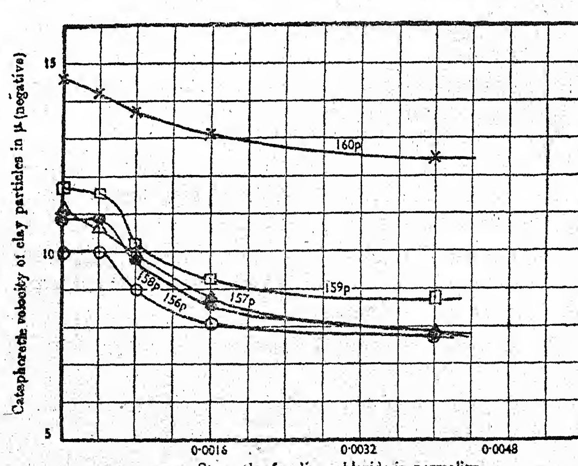

FIG. 1. Bogra soils

small in the case of the Bogra, Bangalore and Pasumalai soils and the variations are considerable with the Midnapore, Jaydebpore, Tellicherry and Bankura soils. The clay fractions from different layers of soil of the same profile shows different initial c.v. pointing to the presence of different clay minerals.

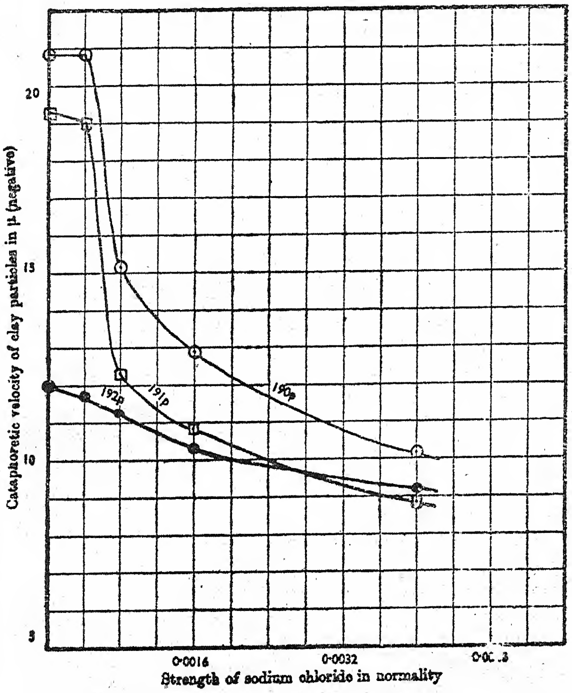

FIG. 2. Tellicherry soils

F. *General conclusions*

From the point of view of the richness of various minerals, soils from the following places appear to be similar: Bogra, Midnapore, Jaydebpore, Pasumalai and Bankura. On the basis of the variations of buffer capacities of the profile samples, it appears that the soils of Jaydebpore, Bankura, Midnapore and Bogra are similar; whilst the profile samples of Pasumalai, Bangalore and Tellicherry possess different buffer characteristics. On the other hand, from the variations of cataphoretic speeds of clay particles with different concentrations of sodium chloride solutions, it appears that the soils of Bogra, Bangalore and Pasumalai are similar, whilst the soils of Midnapore, Jaydebpore, Tellicherry and Bankura form another group of soils. So far as the chemical composition of the clay is concerned, the lowermost layer of soil samples from Jaydebpore, the top and bottom layer of Bangalore profile, all the samples of Tellicherry and the top layer of Bankura profile may be classed as lateritic, whilst all the other samples with which work has been carried out in the present paper should be classed as red loam. As has already been stated from general morphological considerations, the soils of Bogra, Jaydebpore, Pasumalai, Midnapore and Bankura appear as red loam whilst the soils of Tellicherry and Bangalore as lateritic.

SUMMARY

1. The mechanical compositions, base combining capacities and buffer curves of profile samples of red soils collected from several parts of Bengal and Southern India have been examined. The mineralogical compositions of the fine sand fractions and the chemical compositions of the clay fractions have also been determined.

2. From general morphological considerations, the soils of Bogra, Jaydebpore, Pasumalai, Midnapore and Bankura appear as red loam, whilst the soils of Tellicherry and Bangalore appear as lateritic.

3. The percentages of clay fractions are fairly high in all soils except the Tellicherry profile samples, and in all cases except Tellicherry, the percentage clay content shows a maximum value at an intermediate depth of the profile. In general the percentages of coarse sand fractions show minimum values at intermediate depths of the profiles.

4. From the point of view of chemical compositions of clay fractions, none of the soils examined can be classed as laterites. Most of the soils should be classed as red loam (SiO_2/Al_2O_3 of clay fraction $>$ 2·00).

5. The percentages of minerals in the soils vary widely. Soils of Bogra, Midnapore, Jaydebpore, Pasumalai and Bankura are found to be fairly rich in many minerals.

6. On the basis of the variations of buffer capacities of the profile samples, the soils of Jaydebpore, Bankura, Midnapore and Bogra appear to be similar.

7. From the variations of cataphoretic speeds of clay particles with different concentrations of sodium chloride solutions, it appears that the soils of Bogra, Bangalore and Pasumalai are similar whilst the soils of Midnapore, Jaydebpore, Tellicherry and Bankura form another group of soils.

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A CRITICAL STUDY OF THE EFFECT OF SOIL MULCH ON CONSERVATION OF SOIL MOISTURE

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(With one text-figure)

It is commonly believed that an upward movement of water in soil takes place through bundles of narrow capillary tubes, but in case a layer of loose dry soil is formed at the surface the connection between the capillary tubes in the soil is broken off, and water from the subsoil is unable to come up to the surface. Thus, the losses of soil moisture by evaporation are greatly reduced. Keen [1931] in his review of literature has rejected the capillary tube hypothesis, and has come to the conclusion that mulch does not conserve moisture, and cultivation merely helps in the removal of weeds which are responsible for desiccating the soil of its moisture. Much field experimentation has been done to study the effect of mulches on the conservation of moisture, but widely conflicting results have been reported. Kedzie [1889], King [1890], Chilcott and Holm [1897], Fortier and Beckett [1912], Burr [1914], Harris and Bracken [1917], Harris and Jones [1918], McCall [1925], Moomaw and Stoa [1934] and Kuznetsov [1937] maintain that soil mulch is effective in conserving moisture. Recent investigations carried out at Sholapur [1941] also support this view (the mulched plots containing about 30 to 35 per cent more moisture). Experiments conducted by West [1930] in Australia and Esselen [1937] in South Africa show that mulch has a very limited effect. West found that after a period of 30 days the mulched plots contained 5·26 mm. of rain water more than the unmulched plots, and after a period of 23 weeks the difference was equivalent to 3·39 mm. of rain water. On the other hand, Chilcott and Cole [1918] summarizing the results of extensive field experiments conducted by the office of Dry Lands Agriculture, Washington, conclude, that if weeds are not allowed to grow, the loss of moisture from mulched and unmulched plots is the same. Similar conclusions were arrived at by Rotmistrov [1913] Call and Sewell [1917], Alway [1918], Sewell [1919], Veihmeyer [1927], and more recently by Eksteen and Spuy [1941] and Pereira [1941].

Shaw [1929] by conducting experiments under controlled conditions showed that mulches were only effective if the water table existed within a depth of 4 ft. Where no water table is present within 6 ft. soil mulches are ineffective. Etchewery and Harding [1933], have reviewed the entire experimental work on the effect of soil mulches when the water table is deep, and have reached the following conclusions:

1. In soils saturated with moisture (water-logged soils), the mulch is effective in reducing evaporation.

2. In soils having moisture in excess of field capacity but in contact with a continuous water table, soil mulch is effective only when the moisture is excess of field capacity (soils having hard pen form a temporary reservoir of water).

3. In soils where moisture was not in excess of the field capacity soils mulch was not effective in reducing evaporation.

With such conflicting evidences on the subject, it seemed necessary to carry out experiments with a view to study the effect of soil mulch on the conservation of moisture, especially under condi-

tions of low water table (60 to 70 ft.). The importance of the problem is very great from the point of view of dry farming studies. In order to investigate the problem in all its aspects, detailed experiments were carried in the fields, in observation plots and in the pots at the Dry Farming Research Station, Rohtak.

Experimental

Soils. The soil of this tract forms a part of Indogangetic alluvium and is very deep. The water table is at a depth of 60 to 70 ft. The surface soil is medium loam and is fairly uniform in composition. There are great variations, however, in the sub-soil which is comparatively heavy and consists of stiff clay or silty clay, the thickness and depth of which greatly varies. Such a great variation in the sub-soil is mainly responsible for the great heterogeneity which prevails in the soils of this tract. In order to eliminate this factor as much as possible experiments were laid out in randomized blocks, and each treatment was replicated six times.

Moisture determinations were carried out in the usual manner by removing the soil samples with the help of an auger, drying them in weighed boxes at 105°-110°C. in an air oven, and expressing the loss of moisture as percentage on oven dry soil.

Field experiments

Field experiment I

The experiment was laid out in 1936, and was continued over a period of four years. The following four treatments, each replicated six times in randomized blocks were included :

(A) *Desi* plough. (B) S. T. Harrow. (C) Unstirred weeds pulled out. (D) Unstirred plots with weeds on.

Each year all the plots were cultivated till the end of July or beginning of August, before giving any treatment. Plots under treatments (*i*) and (*ii*) were stirred with *Desi* plough and S. T. Harrow respectively, after each shower of rain of half an inch or more. In the third treatment the weeds were scraped off as soon as they made their appearance. In the fourth treatment weeds were allowed to grow. The size of a plot was 1/9th of an acre, and from each plot samples for the estimation of moisture were taken from three different places. Sampling error has been calculated, and it varies from 9 to 3 per cent of the mean. It shows that three samples from each plot were adequate for moisture determination. Each year first sampling was done at the time of giving treatments, and thereafter at fortnightly intervals. First foot was sampled in three sections, viz. 0-3 in., 3-6 in. and 6-12 in. except in 1936 when it was sampled in two sections 0-6 in. and 6-12 in. till 23 September and in three sections on 12 and 28 October. Below the first foot samples were obtained in layers of one foot.

1936. All the plots were cultivated on 1 August, when samples were obtained for the estimation of moisture. The results depicted as percentage on oven dry soil are given in Table I. From 1 August to 10 September a total of 7·50 in. of rain was received. During this period there were no significant differences in the moisture content of the plots under first three treatments except in the lower layers of the plots under weeds which contained slightly less moisture. These results show that there was no effect of cultivation on the absorption of rain water, and the preliminary cultivation given before 1 August, was adequate for effecting maximum absorption. Two more cultivations given after 1 August did not affect the absorption of rain water. After 10 September there were no rains, and there was loss of moisture due to evaporation. Moisture estimated on 23 September showed that the mulched plots contained more moisture than the other plots to 3 ft. depth, but significant differences were observed only in the first 2 ft. layers. From 23 September to 12 October there were further losses of moisture, the loss decreasing with the depth. On this date there was more moisture present in all the layers of mulched plots, and the differences were significant. Before sowing gram, moisture was estimated on 28 October and on this day also there was more moisture in the mulched plots (gains in 0-3 in., 3-6 in., 6-12 in., 2nd foot and 3rd foot being 1·11, 1·88, 1·50, 1·69 and 0·88 per cent, respectively). There was maximum retention of water in 3 in. to 12 in. layer of the soil.

There was no significant difference between the moisture content of plots stirred with *Desi* plough or S. T. Harrow, but average results show that there was slightly less moisture in the lower layers (6-36 in.) of the plots stirred with S. T. Harrow. There were no such differences at the close of rains on 10 September but they developed later on, and were maximum on 12 October.

In the plots with weeds on, moisture was the same as in other plots under different treatments till 27 August, but on 10 September they contained less moisture in the 2nd and 3rd foot layers. Later on there were further losses, and on 28 October there was less moisture in all the layers. Total increase of moisture due to mulching (A-C) and eradication of weeds (C-D) was 76·6 and 88·8 tons per 3 ft. acre respectively.

1937. After harvesting gram on 25 April all the plots were ploughed. Next ploughing was done on 16 July, and on 1 August all plots were stirred with S. T. Harrow. After this date no

TABLE I

Percentage of soil moisture in mulched and unmulched plots on different dates in 1936

Treatments	1-8-36	27-8-36	10-9-36	23-9-36		12-10-36	28-10-36
Rainfall (in.)	10·05	6·31	1·19	..		..	..
0-6 in.					In.		
(A) *Desi* plough	12·77	16·03	16·45	10·23	0-3	5·21	4·28
					3-6	8·96	8·25
(B) S. T. Harrow	13·22	16·13	16·30	10·40	0-3	5·40	4·38
					3-6	8·72	8·38
(C) Weeds pulled out	12·65	15·21	14·65	7·73	0-3	3·92	3·17
					3-6	6·83	6·37
(D) Unstirred with weeds on	13·43	15·95	16·18	6·32	0-3	2·12	6·67
					3-6	4·63	5·10
Observed P	> ·05	> ·05	> ·05	> ·01	0-3	< ·01	< ·01
					3-6	< ·01	< ·01
Critical difference at 5 per cent	..	..	..	1·47	0-3	1·00	0·90
					3-6	1·25	1·47
S. E. per cent mean	2·6	2·2	3·3	5·7	0-3	7·9	8·3
					3-6	5·8	7·0
6-12 in.							
(A) *Desi* plough	14·95	16·20	16·81	13·93		11·47	11·73
(B) S. T. Harrow	16·08	16·63	16·71	13·18		11·78	11·93
(C) Weeds pulled out	14·78	16·10	15·65	12·13		10·08	10·23
(D) Unstirred with weeds on	15·70	16·42	15·16	9·55		8·15	8·44
Observed P	> ·05	> ·05	< ·05	< ·01		< ·05	< ·01
Critical difference at 5 per cent	..	..	1·21	1·24		1·28	1·68
S. E. per cent mean	2·3	2·2	2·5	3·3		4·3	5·3
2nd ft.							
(A) *Desi* plough	15·95	17·30	17·64	16·75		15·03	15·08
(B) S. T. Harrow	15·27	17·73	17·63	16·10		14·47	14·40
(C) Weeds pulled out	13·60	17·03	16·70	14·97		13·62	13·39
(D) Unstirred with weeds on	16·48	16·82	15·00	13·51		11·41	12·62
Observed P	< ·01	> ·05	< ·01	< ·01		< ·05	< ·01
Critical difference at 5 per cent	1·39	..	1·26	1·37		1·90	0·87
S. E. per cent mean	3·0	1·7	2·9	2·9		4·6	2·1
3rd ft.							
(A) *Desi* plough	14·32	17·17	18·03	17·47		16·86	12·26
(B) S. T. Harrow	12·92	17·30	17·88	16·40		16·16	15·84
(C) Weeds pulled out	11·65	16·38	17·25	15·88		15·41	15·38
(D) Unstirred with weeds on	15·33	16·98	16·28	14·52		12·62	13·13
Observed P	< ·05	> ·05	< ·01	< ·05		< ·01	< ·01
Critical difference at 5 per cent	2·36	..	1·06	1·85		1·15	0·79
S. E. per cent mean	5·8	4·2	2·1	3·7		2·5	1·7

cultivation was given to the plots under treatment (*iii*) and (*iv*). First sampling for the estimation of moisture was done on 3 August, and afterwards at fortnightly intervals. The data are given in Table II. Before 3 August, there was 9·13 in. of rain, and due to it there was more moisture in the cultivated plots and those cultivated with *Desi* plough contained the highest. From 1 to 19 August there were no rains and there was loss in moisture from the entire 3 ft. column of the soil. In 0-3 in. layer of the mulched plots there was more moisture than unmulched plots, though in the lower layers there was no difference. On 29 and 30 August, there occurred 0·96 in. of rain, and moisture was estimated on 1 September. There was no difference of moisture in the plots under first three treatments, though in the plots with weeds on there was less moisture. From 14 to 16 September 2·26 in. of rain were received, and this caused an increase of moisture in the entire 3 ft. column of the soil. Moisture estimated on 20 September showed that there was no difference in the first 3 in. of the plots under all

the treatments, though in the lower layers there was less moisture in the plots with weeds on. From 20 September to 18 October there were no rains, and there was loss of moisture due to evaporation. Maximum losses took place in 0-3 in. layers. Losses from the lower layers were less, and there was no loss of moisture below first foot. On 4 October in the first 12 in. the mulched plots contained more moisture than in the unmulched plots without weeds. On 18 October before sowing of gram crop there was more moisture in the first foot layer of the mulched plots.

Table II

Percentage of soil moisture present in mulched and unmulched plots on different dates in 1937

(Soil moisture as percentage on oven-dry soil)

Dates	(3-8-37)	(19-8-37)	(1-9-37)	(20-9-37)	(4-10-37)	(18-10-37)
0-3 in.						
Rainfall (in.)	9·13	..	0·96	2·26	..	..
(A) *Desi* plough	4·95	4·90	7·52	12·00	5·92	5·62
(B) S. T. Harrow	3·26	5·26	7·86	11·73	6·51	7·17
(C) Weeds pulled out	..	4·04	7·31	10·78	5·73	4·54
(D) Unstirred with weeds on	..	3·64	6·51	10·08	5·49	4·05
Observed P	..	< ·05	< ·05	> ·05	< ·05	< ·01
Critical difference at 5 per cent	..	1·06	0·86	..	0·94	0·87
S. E. per cent mean	..	8·1	3·9	4·8	5·5	5·6
3-6 in.						
(A) *Desi* plough	14·35	7·87	9·73	14·53	10·17	9·44
(B) S. T. Harrow	13·00	8·04	10·03	14·60	10·30	9·89
(C) Weeds pulled out	11·01.	71·24	9·64	13·66	8·70	7·76
(D) Unstirred with weeds on	11·22	6·35	7·73	12·68	7·93	7·33
Observed P	< ·01	> ·05	< ·01	< ·01	< ·05	< ·01
Critical difference at 5 per cent	1·21	..	0·98	1·13	1·29	1·20
S. E. per cent mean	3·2	6·3	3·5	2·7	4·6	4·9
6-12 in.						
(A) *Desi* plough	15·48	10·92	11·38	16·00	13·43	12·61
(B) S. T. Harrow	14·60	11·46	11·42	15·56	13·28	12·39
(C) Weeds pulled out	13·70	11·11	11·58	14·36	12·42	11·27
(D) Unstirred with weeds on	13·30	9·41	8·25	12·97	9·76	9·27
Observed P	< ·01	< ·01	< ·01	< ·01	< ·01	< ·01
Critical difference at 5 per cent	0·85	1·15	1·02	2·9	0·81	0·99
S. E. per cent mean	2·0	3·8	3·1	1·28	7·3	2·9
2nd ft.						
(A) *Desi* plough	16·12	13·60	13·52	15·77	15·19	14·52
(B) S. T. Harrow	14·66	12·86	13·33	14·68	14·29	14·27
(C) Weeds pulled out	14·05	13·49	13·23	14·28	14·07	13·86
(D) Unstirred with weeds on	14·60	12·57	10·92	10·58	10·30	10·22
Observed P	< ·05	> ·05	< ·01	< ·01	< ·01	< ·01
Critical difference at 5 per cent	1·36	..	1·30	3·9	2·00	1·49
S. E. per cent mean	3·0	2·4	3·4	1·62	4·9	3·6
3rd ft.						
(A) *Desi* plough	14·21	12·68	13·45	14·30	14·33	13·84
(B) S. T. Harrow	12·42	12·60	12·73	13·10	13·93	14·05
(C) Weeds pulled out	14·03	13·97	14·05	14·47	14·70	14·34
(D) Unstirred with weeds on	14·74	13·07	12·73	10·45	11·02	11·25
Observed P	< ·05	> ·05	> ·05	< ·01	< ·01	< ·01
Critical difference at 5 per cent	..	..	..	0·71	1·24	1·27
S. E. per cent mean	3·5	3·6	3·4	1·8	3·0	3·7

There were no significant differences in the moisture content of the plots cultivated with *Desi* plough and S. T. Harrow except on 18 October when there was more moisture in 0-3 in. layer of the soil cultivated with S. T. Harrow.

Till 19 August, weeds removed moisture only from 2 ft. layer of the soil, but on 1 September they tapped from the third foot layer also. Later on more moisture was removed by the weeds, and there was further decrease in the moisture content of all the layers down to third foot. There were no significant differences in the first 6 in. of the plots from which weeds were removed and those with weeds on. Bulk of the moisture removed by the weeds came from 6 to 24 in. of the soil.

During this year, there was significant increase only in the first foot layer of the mulched plots, the maximum increase in 0-3 in., 3-6 in. and 6-12 in. layers being 2·63, 2·13 and 1·12 per cent, respectively. The maximum saving of moisture due to mulching (B-C) and eradication of weeds (C-D) was 35·9 and 149·6 tons per 3-ft. acre.

1938. After harvesting gram all the plots were ploughed on 2 April. The rainfall during this year was below normal, and was received in very small showers. Consequently, moisture in the soil remained very low. First sampling was done on 3 August after a total rainfall of 5·68 in. After this date no cultivation was given to the unstirred plots. Moisture was estimated on 28 August after 0·56 in. of rain. and again on 3 September after 0·92 in. of rain, On these dates the moisture content under different treatments was more or less the same. Next sampling was done on 19 September and during this interval no rain was received. Losses of moisture occurred in the first foot layer and the moisture content in three inches layer varied between 2·95 and 2·24 per cent which is below its hygroscopic coefficient. The results of moisture determination are given in Table III.

TABLE III

Percentage of soil moisture present in mulched and unmulched plots on different dates in 1938

(Moisture as percentage on oven-dry soil)

	3-9-38					19-9-38				
	0-3 in.	3-6 in.	6-12 in.	2nd ft.	3rd ft.	0-3 in.	3-6 in.	6-12 in.	2nd	3rd ft.
A	7·54	9·49	8·72	9·44	11·53	2·27	5·45	7·73	9·53	11·56
B	7·52	9·42	8·27	9·13	11·88	2·95	5·88	8·16	9·54	11·95
C	6·60	8·90	9·30	10·16	11·86	2·24	5·29	8·28	9·90	12·15
D	7·66	10·14	9·82	9·72	11·38	2·34	4·33	6·63	9·15	11·03
Observed P . .	$>\cdot05$	$>\cdot05$	$>\cdot05$	$>\cdot05$	$>\cdot05$	$<\cdot05$	$<\cdot05$	$<\cdot01$	$>\cdot05$	$<\cdot05$
Critical difference at 5 per cent . .	..	..	..	..	..	0·55	0·92	0·70	..	0·77
S. E. per cent mean.	4·9	5·9	4·4	8·1	2·7	7·3	5·7	3·1	2·7	2·1

During this year there were no significant differences in the mulched and unmulched plots except that in 0-3 in. layer of the plots stirred with S. T. Harrow significantly more moisture was present than in plots under other treatments. In the plots under weeds there was less moisture in all the layers between 3 and 36 in. Loss of moisture due to weeds amounted to 54·8 tons per 3 ft. acre.

1939. The experiment was laid out on 20 July and the total rainfall received up to that date was 4·54 in. Moisture was estimated on this date and afterwards at 7 to 15 days interval. The results of moisture determinations are given in Table IV.

On 20 July there was no difference in the moisture content of the plots under all the treatments. From 20 to 27 July, no rains were received and there was loss of moisture from the first foot layers. No appreciable difference was observed in the moisture content of the mulched and unmulched weeded plots, though decrease of moisture occurred in the plots with weeds on. On 8 August, there occurred 0·62 in. of rainfall, and this caused an increase in the moisture content of the first 6 in. layer of the soil. There was no significant difference in the mulched and unmulched weeded plots, but in the plots with weeds on there was less moisture. From 9 to 19 August no rains were received, and during this period there was more moisture in 0-3 in. layer of the mulched plots, but in the lower layers there were no significant differences between the mulched and unmulched weeded plots though the moisture content was greater than the plots with weeds on. Between 4 and 18 September there were 1·38 in. of rain and this caused an increase in the moisture content of the first 2 ft. layer of the soil. There was no difference in the moisture content of the mulched and unmulched weeded plots except that there was more moisture in 0-3 in. layer of weeded plots. In the plots with

weeds on there was less moisture in the entire three feet column. Final estimation of moisture was carried out on 10 October before sowing barley, when there was more moisture in the first foot layer of the mulched plots than in the mulched weeded plots, though in the lower layers it was more or less the same.

Weeds had removed moisture from the entire 3 ft. column of the soil, and the plots with weeds on contained less moisture throughout.

During this year increase due to mulch (A-C) was significant in the first foot layer only, increase in 0-3 in., 3-6 in. and 6-12 in. being 0·78, 0·84, and 1·84 per cent respectively. The total increase due to mulching (A-C) was small, and amounted to 31·05 tons per three feet acre. The moisture taken up by the weeds was large and the total moisture removed (C-D) from 3 ft. column amounted to 160·5 tons per 3-ft. acre.

Effect of weeds on soil moisture

The results of the field experiments show that weeds generally desiccate the soil of its moisture. In top 3-ft. layer there has always been less moisture in the plots with weeds on than those without weeds. The gain of moisture due to removal of weeds in the year 1936, 1937, 1938 and 1939 amounted to 88·8, 149·6, 54·8 and 160·5 tons of water per 3 ft. acre, respectively.

Table IV

Percentage of soil moisture present in mulched and unmulched plots on different dates in 1939

Treatment	20-7-39	27-7-39	9-8-39	19-8-39	26-8-39	4-9-39	18-9-39	10-10-39
Rainfall (in.)	4·54	..	0·62	..	..	0·38	1·38	..
0-3 in.								
(A) *Desi* plough	9·89	5·50	10·04	4·95	3·38	5·93	10·65	4·06
(B) S. T. Harrow	8·96	6·21	10·18	4·43	3·72	4·95	9·58	3·60
(C) Weeds pulled out	9·40	6·72	9·07	3·86	2·92	4·35	12·08	3·28
(D) Unstirred with weeds on	9·31	4·01	8·75	2·04	1·29	4·18	9·61	2·40
Observed P	> ·05	< ·01	< ·05	< ·01	< ·01	< ·01	< ·05	< ·01
Critical differences at 5 per cent	..	1·23	1·70	1·05	1·07	0·66	1·70	0·70
S. E. per cent mean	6·5	7·3	6·0	9·2	12·4	4·5	5·7	7·2
3-6 in.								
(A) *Desi* plough	12·05	8·35	11·39	7·67	5·61	7·31	12·75	7·05
(B) S. T. Harrow	11·97	8·58	10·52	7·25	6·34	6·78	11·07	6·58
(C) Weeds pulled out	11·54	8·67	9·94	6·93	5·68	6·21	12·02	6·21
(D) Unstirred with weeds on	11·80	5·99	7·14	3·81	2·68	4·84	10·72	4·05
Observed P	> ·05	< ·01	< ·01	< ·01	< ·01	< ·01	> ·05	< ·01
Critical differences at 5 per cent	..	1·02	1·88	1·04	0·94	1·49	..	0·30
S. E. per cent mean	4·6	4·0	6·5	5·5	6·0	7·9	4·9	1·7
6-12 in.								
(A) *Desi* plough	11·56	10·07	11·67	10·19	7·75	10·14	12·45	9·74
(B) S. T. Harrow	10·43	10·65	10·78	9·51	8·93	9·46	10·63	9·26
(C) Weeds pulled out	11·00	10·48	9·92	9·73	8·80	8·56	11·35	7·89
(D) Unstirred with weeds on	10·21	7·92	6·58	5·68	4·70	5·69	8·31	6·79
Observed P	> ·05	< ·01	< ·01	< ·01	< ·01	< ·01	< ·01	< ·01
Critical differences at 5 per cent.	..	1·32	1·55	1·49	1·60	0·96	2·00	1·28
S. E. per cent. mean	5·9	4·5	5·0	5·7	7·1	4·2	6·2	5·0
2nd ft.								
(A) *Desi* plough	11·05	..	11·95	..	..	11·38	12·15	11·68
(B) S. T. Harrow	10·19	..	11·11	..	..	10·35	10·70	11·01
(C) Weeds pulled out	10·80	..	10·74	..	..	10·35	10·62	11·65
(D) Unstirred with weeds on	8·87	..	7·70	..	..	7·06	7·10	7·86
Observed P	> ·05	..	< ·01	..	..	< ·01	> ·01	< ·01
Critical differences at 5 per cent	..	..	1·26	..	..	1·09	1·34	1·07
S. E. per cent mean	5·8	..	3·9	..	..	3·7	4·4	3·3
3rd ft.								
(A) *Desi* plough	11·41	..	..	..	..	12·08	11·60	12·56
(B) S. T. Harrow	11·29	..	..	..	..	11·87	11·65	12·37
(C) Weeds pulled out	11·36	..	..	..	..	12·26	11·10	12·27
(D) Unstirred with weeds on	10·55	..	..	..	..	18·76	8·15	8·84
Observed P	> ·05	..	..	..	..	< ·01	< ·01	< ·01
Critical difference at 5 per cent	..	..	..	..	..	0·94	1·56	0·80
S. E. per cent mean	1·5	..	..	..	..	2·2	4·9	4·7

Further experiments were carried out to find the amount of moisture removed by the weeds from the deeper layers. Two plots were laid out in field 78, weeds were scraped off from one plot while in the other they were allowed to grow. Moisture was estimated to 6 ft. depth, and the results are given in Table V.

TABLE V

The effect of weeds on soil moisture

(Percentage on oven-dry soil)

Depth	1-8-37		23-9-39		13-2-40		31-5-40		16-9-41		Wilting coefficient*
	Without weeds	With weeds	Without weeds	With weeds	Without weeds	With- weeds	Without weeds	With weeds	Without weeds	With weeds	
0-6 in.	15·08	16·44	8·02	3·50	14·78	11·69	3·66	1·54	6·40	1·74	2·85
6-12 in.	15·50	15·82	10·92	4·65	15·61	12·71	7·86	4·71	8·19	2·23	3·45
2nd ft.	12·67	7·73	10·58	5·45	16·88	8·35	12·44	6·49	10·89	3·86	3·32
3rd ft.	14·43	9·93	11·78	6·62	14·82	8·35	13·11	7·71	11·33	5·19	2·88
4th ft.	14·20	10·60	11·96	6·96	13·77	6·95	12·58	7·64	11·09	5·79	4·20
5th ft.	11·95	10·79	9·94	4·93	9·15	4·70	10·77	5·15	7·99	3·84	4·35
6th ft.	9·01	8·42	8·59	3·20	7·31	3·64	8·22	3·50	5·78	2·68	2·19
Average moisture	12·93	10·60	10·39	5·20	10·35	5·37	10·48	5·60	9·06	3·97	..
Water removed (in.)	2·63		5·86		5·62		5·51		5·75		

* Wilting coefficient given in the last column of Table V was calculated from hydroscopic coefficient by the formula of Briggs and Shantz [1912].

On 18 September 1937, moisture was estimated two days after a shower of 2·62 in. of rain. Though the moisture in the first foot layer of the plots with weeds and without weeds was the same yet in the lower layers there was 2·63 in. of more moisture in the plots without weeds. On other dates except 31 May 1940 moisture was estimated six to seven days after the rains, but on 31 May 1940 samples were obtained before the onset of monsoons. Throughout this period the water removed by the weeds varied from 5·86 to 5·51 in. Weeds greatly desiccated the soil of its moisture, which in the first foot on 16 September 1941 and 0-6 in. on 31 May 1940 fell below the wilting coefficient, while in the lower layers it was about the wilting coefficient.

Field experiment II

In 1940 a complex experiment was laid out to study the effect of mulching alone and in combination with manuring on the conservation of soil moisture. There were four treatments, and each treatment was replicated six times. Farmyard compost was added at 2½ tons per acre a month before the sowing of the crop. The experiment was conducted for three years from 1940 to 1942. Moisture down to six feet depth was estimated before sowing barley. As in the first experiment the first foot was sampled in three sections, 0-3 in., 3-6 in. and 6-12 in. Since there was no significant effect of different treatments on the moisture content below first foot, moisture data pertaining to first foot only are given in Table VI.

TABLE VI

The effect of mulching and manuring on soil moisture

(Moisture as percentage on oven-dry soil)

	27-10-40			21-10-41			20-10-42		
	0-3 in.	3-6 in.	6-12 in.	0-3 in.	3-6 in.	6-12 in.	0-3 in.	3-6 in.	6-12 in.
A. Mulching manuring	3·84	7·04	10·52	5·17	8·11	11·26	7·10	10·75	12·90
B. Mulching no manuring	4·08	7·47	10·93	4·97	8·06	11·25	7·12	10·86	13·14
C. No mulching manuring	3·09	6·21	10·18	3·88	7·49	10·94	5·85	9·63	12·17
D. No mulching no manuring	3·27	5·97	10·11	3·80	7·39	10·87	5·44	9·20	·65
Observed P.	<·01	<·01	>·01	<·01	<·01	>·05	<·01	<·01	<·01
Critical difference at 5 per cent	0·60	0·52	..	1·01	0·61	..	0·53	0·44	0·69
S. E. per cent mean	6·3	2·4	2·7	7·9	7·8	3·6	2·8	1·5	1·9

In each year there has been more moisture in the mulched plots, and there was no effect of Farmyard compost on the conservation of moisture. In 1940, 1941 and 1942, there occurred 11·91, 11·31 and 24·92 in. of rain, respectively. Differences were significant in the first 6 in. layer in 1940 and 1941 while they were significant in all depths down to first foot in 1942. Increase of moisture due to mulch formation was about 33 per cent of the moisture in the unmulched plots.

Observation plots

In the field experiments, the effect of mulch on the conservation of moisture was studied till the sowing of winter crops in October, and these being randomized experiments the effect of mulch on soils of varying mechanical composition could not be studied. In order to investigate this aspect of the problem plots (33 ft. $\times 16\frac{1}{2}$ ft.) were laid out in two fields representing the two extreme types of soil at the station, and moisture was estimated throughout the year. In each field, there were two plots, one was stirred with spade to form soil mulch 3 in. deep, and the other was not stirred but weeds were removed by scraping. Moisture was estimated down to 2 ft. depth. The experiment was continued for a period of two years, 1936-38. Each year the first sampling was done after the close of rains in the month of September, and afterwards samples were obtained at seven to fifteen days interval. One bore was taken each time from each plot and the distance between two bores taken on two consecutive dates was 3 ft. The results of moisture determinations are given in Tables VIII (*a*) and (*b*).

Texture of the plots. Plots 33 ft. long and $16\frac{1}{2}$ ft. wide were laid out in fields 92 and 78. The surface soil of field 92 is medium loam, and contains 16·31 per cent of clay and 35·80 per cent of silt, while that of the field 78 is light loam and has 9·25 per cent of clay and 24·30 per cent of silt. The soil of both the fields tends to become heavy in the sub-soil, but in the lower layers of field 92 there is about 23 to 39 per cent more clay *plus* silt fraction than in field 78. Mechanical analyses of both the fields to a depth of 3 ft. are given in Table VII.

Table VII

Mechanical composition of soil under mulched and unmulched plots

(Percentage on oven-dry soil)

Depth	Field 92				Field 78			
	Clay 0·002 mm.	Silt 0·02 mm.	F. Sand 0·20 mm.	C. Sand 2·0 mm.	Clay 0·002 mm.	Silt 0·02 mm.	F. Sand 0·20 mm.	C. Sand 2·0 mm.
0-6 in.	16·31	35·80	50·38	*Nil*	9·25	24·30	65·38	1·07
6-12 in.	21·65	40·04	38·25	0·05	13·50	19·32	67·50	1·59
2nd ft.	34·08	32·58	31·52	0·53	21·02	22·36	54·95	1·08
3rd ft.	39·92	40·12	16·59	1·10	23·04	26·88	51·95	1·03

1936-37. The data from this experiment support the conclusion drawn from the field experiments that soil mulch conserves moisture and over a certain period there is more moisture in the surface foot of the stirred plots than in the unstirred ones. The differences are more marked in the case of heavy soil than in the case of light soil. In the year 1936 there were no rains from 6 September to 5 December. During this period it was observed that there was more moisture in 0-6 in. layer of the mulched plots but the differences were more in the case of the heavy soil than in the light one. In the light soil the differences became very small in the beginning of November but these were still large in the heavy type. From 9 to 11 February 4·31 in. of rain was received. Moisture estimated on 18 February showed that it was almost the same in the mulched and unmulched plots of the field 78 but there was slightly more moisture in 0-6 in. layer of the mulched plots of the field 92. Later on, differences became more and there was always higher moisture in the mulched plots. In the light soil the differences became very small by the end of April but in the heavy type the differences were large and these existed till the break of monsoons in the beginning of June (Fig. 1).

1937-38. In the year 1937, there were no rains from 16 September to the end of December. During this period, it was observed, that there was more moisture in the case of mulched plots of field 78 to the end of November, and in field 92 till the end of December, when a shower of 1·27 in. was recorded on the 1st of January. This was again followed by a dry period. Till

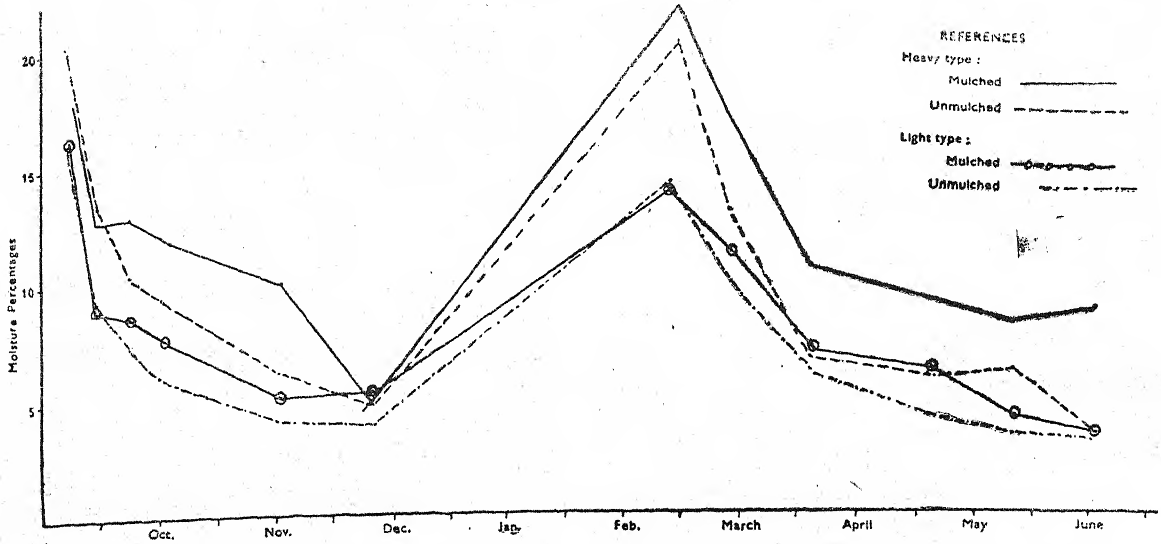

FIG. 1. Effect of soil mulch on soils of different texure (1936-37)

April the difference in moisture between the mulched and unmulched plots were small but later on differences became more marked and there was higher moisture in the mulched plots till the break of monsoons. The results from these plots show that over a certain period there was more moisture in the mulched plots than in the unmulched plots. The differences this year were also more in the heavy type than in the light one. In the year 1936, when rains were more the differences of moisture between the mulched and unmulched plots were more marked than in the year 1937 when the rains were less.

POT EXPERIMENT

A pot experiment to find out the optimum depth of the soil mulch which can effect maximum conservation of moisture was started on 20 July 1937. Treatments were (*i*) 2 in. deep mulch, (*ii*) 4 in. deep mulch, (*iii*) 6 in. deep mulch, and (*iv*) control. Four replications of each treatment were arranged.

TABLE VIII (*a*)

Moisture percentage affected by mulching in soils of different mechanical composition

(Moisture as percentage on oven-dry soil)

	8-9-36	16-9-36	24-9-36	3-10-36	3-11-36	27-11-36	18-2-37	1-3-37	22-3-37	23-4-37	13-5-37	4-6-37
Rainfall (in.)	1·12	0·07	0·0	0·0	0·0	0·0	5·17	0·0	0·0	0·0	0·10	0·21
FIELD NO. 92												
0-6 in.												
Mulched . . .	18·16	12·71	12·99	12·16	10·33	5·09	21·88	17·27	10·66	9·07	7·91	8·55
Unmulched . . .	20·55	13·63	10·58	9·52	6·45	5·11	20·54	13·06	6·78	5·81	5·93	3·39
6-12 in.												
Mulched . . .	18·51	16·62	15·24	16·37	15·67	11·44	22·35	19·33	16·64	14·65	13·78	15·10
Unmulched . . .	18·56	18·38	15·29	16·54	11·83	11·98	22·26	15·05	11·53	12·43	12·76	9·68
2nd ft.												
Mulched . . .	18·26	17·46	17·35	17·62	16·54	13·97	20·51	20·28	19·14	19·90	19·26	16·24
Unmulched . . .	19·11	18·15	17·88	14·09	15·96	14·14	23·12	16·77	14·11	14·40	14·86	14·54
FIELD NO. 78												
0-6 in.												
Mulched . . .	16·66	8·91	8·73	7·81	5·28	5·47	14·00	11·31	7·13	6·13	3·93	3·60
Unmulched . . .	15·96	9·37	7·66	6·03	4·67	4·62	14·24	10·08	5·89	4·19	3·22	2·85
6-12 in.												
Mulched . . .	15·34	10·80	10·81	10·50	8·54	8·39	16·05	12·31	9·27	9·08	7·80	7·09
Unmulched . . .	15·45	12·24	10·01	10·24	8·21	8·33	15·31	12·53	9·98	9·75	7·78	7·65
2nd ft.												
Mulched . . .	15·29	14·33	15·99	13·71	11·05	10·36	16·22	12·96	13·12	11·81	11·88	7·56
Unmulched . . .	13·73	13·58	13·46	12·24	11·40	10·26	15·15	13·45	11·54	12·46	11·35	6·29

TABLE VIII (*b*)

Moisture percentage affected by mulching in soils of different mechanical composition

(Moisture as percentage on oven-dry soil)

1937-38

	18-9-37	27-9-37	30-10-37	2-12-37	23-12-37	3-1-38	14-1-38	15-2-38	17-3-38	15-4-38	16-5-38	27-5-38	7-6-38
Rainfall (in.)	2·69	0·0	0·0	0·0	0·02	1·27	0·0	0·22	0·01	0·0	0·27	0·0	0·18
FIELD NO. 92													
0-6 in.													
Mulched . .	18·66	13·75	8·97	7·07	6·48	17·27	11·52	7·48	6·32	4·59	3·57	2·87	3·11
Unmulched .	15·79	8·53	5·80	4·68	4·81	15·75	10·14	8·04	6·28	4·94	2·19	2·23	2·47
6-12 in.													
Mulched . .	18·02	15·90	13·13	12·22	10·37	14·44	14·22	11·59	11·49	9·15	8·37	5·94	5·19
Unmulched .	15·96	11·27	11·20	9·46	9·68	13·46	12·66	11·16	12·36	10·30	5·55	4·55	4·68
2nd ft.													
Mulched . .	14·20	15·00	13·30	12·77	12·33	13·65	14·07	14·11	12·77	13·30	10·65	9·96	10·40
Unmulched .	15·74	15·61	14·56	9·30	10·32	15·10	15·00	14·67	13·14	14·58	11·57	11·15	9·90
FIELD NO. 78													
0-6 in.													
Mulched . .	16·56	10·97	7·07	6·53	5·98	14·46	12·17	6·87	6·09	5·87	6·53	4·79	4·42
Unmulched .	14·76	9·48	5·64	6·40	6·18	15·00	12·15	6·08	5·67	4·16	5·50	3·62	3·73
6-12 in.													
Mulched . .	16·57	13·85	10·68	8·98	9·24	12·59	11·86	9·96	10·29	8·70	8·56	8·88	8·30
Unmulched .	15·86	12·31	8·86	8·59	9·27	13·86	12·58	8·68	9·19	8·11	7·93	6·91	7·84
2nd ft.													
Mulched . .	17·21	15·20	12·09	12·01	11·57	11·46	11·54	12·87	12·58	12·28	11·23	11·47	12·41
Unmulched .	14·22	13·67	11·47	12·58	12·96	13·71	12·47	11·47	12·50	12·13	11·78	10·87	12·31

Equal amount of water was added to each plot in the beginning, and pots were occassionally weighed. Losses from 20 to 26 July were the same from mulched and unmulched plots, being 7·1 lb. On 26 July 1937 all the pots attained 'watar' when they were stirred except the control pots which were kept unstirred. After the formation of mulch, losses from the mulched pots greatly decreased, losses from mulched and unmulched pots on 9 August 1937 being 1·5 and 4·3 lb., respectively. Later on losses from the unmulched pots began to decrease, and from 13 October to 21 December, there were more losses from the mulched pots than from the unmulched pots, the losses being 4·0 and 1·6 lb., respectively. The total loss of moisture was more from unmulched pots than from mulched pots.

To find out the distribution of moisture in pots under different treatments moisture was estimated on 13 October. For this purpose samples were removed in three sections, 0-3 in., 3-6 in., 6-12 in. Average results of four replications are given in Table IX.

TABLE IX

The effect of mulches of different depths on soil moisture

	2 in.	4 in.	6 in.	Control	Observed P.	C. D.	S. E. per cent
0-3 in.	7·59	7·84	7·17	2·97	$<\cdot01$	3·76	12·6
3-6 in.	9·83	10·18	9·66	8·09	$<\cdot01$	2·08	8·1
6-12 in.	10·13	12·96	13·06	9·98	$<\cdot01$	2·48	6·5

The above data definitely show, that soil mulch helps in the conservation of moisture. Though in 0-3 in. layer of the control pots moisture had fallen to 2·97 per cent which is below the wilting coefficient, yet under soil mulch it was 7·71 to 7 84 per cent. In all the layers, moisture under soil mulch was appreciably more than in the control pots.

When the effect of mulches of varying depth is compared, it is observed that maximum conservation is effected under 4 in. deep soil mulch. Under 2 in. soil mulch there was about 1·6 per cent less moisture than that under 4 in. or 6 in. soil mulch. Though there were no significant differences in the moisture conserved by 4 in. or 6 in. mulch but the average results show that there was more moisture under 4 in. mulch. These observations suggest that 4 in. soil mulch is the best for effecting maximum conservation of soil moisture, and a shallow mulch is as good as a deep mulch.

Discussion

The work reported in the foregoing pages was carried out over a period of seven years, which recorded great fluctuations in the amount of rainfall received from year to year. In summer 1938, 6·73 in. were received, which is much below the normal (13·27), while during the same period in 1942, 24·92 in. were recorded, which is nearly double the normal. The results reported clearly show that in every year there was more moisture in the mulched plots, though the amount thus conserved greatly differed during different seasons. Increase of moisture due to soil mulch in every layer to 3 ft. depth, percentage moisture present in 0-6 in. layer of the soil at the close of monsoons in September, and rainfall are given in Table X.

A correlation of moisture content in 0-6 in. layer and the water conserved in the same layer has been worked out. There exists a high correlation between the moisture present at the time

TABLE X

Increase of moisture in the mulched plots at the time of sowing of crop

Depth	1936	1937	1938	1939	1940	1941	1942
0-3 in.	1·11	1·08	0·71	0·78	0·81	1·17	1·78
3-6 in.	1·88	1·68	0·59	0·84	1·50	0·67	1·66
6-12 in.	1·50	1·34	0·12	1·85	0·82	0·38	0·94
2nd ft.	1·69	0·66	0·36	0·03	0·21	0·59	0·71
3rd ft.	0·88	0·49	0·20	0·29	1·23	1·90	0·36
Moisture on 0-6 in. at the close of rains	16·45	13·27	8·51	10·99	11·21	12·69	17·07
Rainfall in inches	17·55	12·92	6·73	7·35	10·91	11·13	24·92

of close of rains and increase in moisture due to soil mulch. The calculated correlation comes to 0·8839 which is significant at 1 per cent level. In the years 1936 and 1942 when the rains were above normal and the moisture in 0-6 in. layer was 16·45 and 17·07 per cent respectively, increase of moisture due to mulching was more than in other years when the rains and moisture in 0-6 in. were less. In the year 1936 and 1942 mulching effected increase in the entire 3-ft. column, though in other years its effect was limited to first 6 or 12 in. layer. In the year 1938 when there were 6·73 in. of rain, and moisture in 0-6-in. layer was 8 51 per cent, the significant increase was only in 0-3 in. layer of soil. The results show that the conservation of moisture by mulch depends on the moisture in the surface layer, or in other words on the rainfall received before the sowing of crop. The effect of mulch starts from the surface and extends downward depending on the moisture content.

Leather [1908] developing on Brigg's [1897] hypothesis assumes that capillarity starts from the surface and gradually goes down as evaporation proceeds. Due to evaporation there is loss of moisture from the surface and there is curvature in water films. The curvature of the air water interfaces increases, and the moisture in surface layer is always in a state of tension, and in order to reduce its curvature it sucks water from the layer of soil beneath it. This layer in turn draws moisture from the layer immediately below it, and so does the next layer and so on, until the suction pressure due to curvature of the air water interfaces, which decreases with the depth becomes so small that it can only draw negligibly small quantity of water from the next layer. This limit is put down as 7 ft. by Leather [1908], 3 ft. by Sen [1930], and 21 in. by Carbery and Chakladar [1936]. The data obtained by us shows that the depth from which water will be drawn to the surface depends on the moisture content of the soil. In 1938, when the moisture content of the 3 ft. layer was low (9·86 per cent), evaporation occurred from the first 6 in. only, though significant losses were obtained from the first 3 in. layer, and in 1936, when it was high (17·43 per cent), there were losses from the entire 3-ft. column of the soil.

Mulching retards evaporation, and it is only over a certain period that there is more moisture in mulched than in unmulched plots. Lower

limit to which moisture is reduced by evaporation in soil depends on the mateorological factors and the nature of the soil. The unmulched plots attain this lower limit earlier than the mulched plots. Under the conditions prevailing at Rohtak, there is more moisture in the mulched than in the unmulched plots over a period of two to three months.

The mulch as already observed conserves moisture, and maximum differences due to it take place in the surface 6-in. Workers like Veihmeyer [1927], Alway [1918], and others obtained samples in sections of 1-ft., and perhaps for that reason they were unable to observe any appreciable effect of soil mulch. Veihmeyer [1927] though maintained that mulching had no effect yet his experiments at Delhi with tanks under six inch mulch indicate that soil mulch effects conservation. The results of the experiments conducted by Esselen [1937], and Eksteen and Spuy [1941], in South Africa clearly showed that there was always more moisture in 0-6 in. layer of mulched plots, but these workers do not consider these differences of any economic value.

Value of mulch in the soils of Rohtak tract

The question now arises whether it would be economical to maintain soil mulch when it has been observed that soil mulch has limited effect only. Under these conditions the rains generally stop in the first week of September, and the winter crops are sown after the middle of October. If no mulch is produced, moisture in surface six inches, where seed is to be sown is greatly reduced and falls short of that required for good germination. Germination counts * were taken in the mulched and unmulched plots sown with barley in the years 1939, 1940, 1942 and results are given in Table XI.

* Germination counts were taken by Mr I. M. Rao, Plant Physiologist, for which authors are thankful to him

TABLE XI

The effect of mulching on germination counts

(Mean per unit of 4 adjacent rows each one meter long)

	1939		1940		1942	
	Mulched	Unmulched	Mulched	Unmulched	Mulched	Unmulched
	24·6	18·1	54·5	41·0	57·6	48·5
Observed P	<·05		<·01		<·01	
S. E. per cent mean	6·6		9·7		7·8	

There has always been better germination in the mulched plots and the differences have been statistically significant.

Yield data for five years are available and these are given in Table XII.

TABLE XII

Yields of grain in pounds per acre from mulched and unmulched plots

	Gram				Barley					
	1936-37		1937-38		1940-41		1941-42		1942-43	
	Mulched	Un-mulched	Mulched	Un-mulched	Mulched	Un-mulched	Mulched	Un-mulched	Mulched	Un-mulched
	880	397	329	250	892	713	423	265	1277	1006
Observed P	<·01		<·01		<·05		<·05		<·01	
S. E. per cent mean.	16·6		9·8		7·5		16·0		6·6	

Gram was sown in 1936 and 1937, and barley was sown in 1940, 1941 and 1942 and both the crops from mulched plots gave better yields than those from the unmulched plots. In 1936 there was difference of 483 lb. per acre in mulched and unmulched plots, but in 1937 difference was small being only 79 lb. In 1936 sowings were done on 28 October and moisture present in 0-6 in. layer of the mulched and unmulched plots was 6·5 and 4·7 per cent respectively. In 1937-38 moisture in the mulched and unmulched plots at the time of sowing on 18 October 1937 was 7·78 and 6·13 per cent respectively.

Moisture in the surface layer at the time of sowing in 1936 was lower than in 1937, especially in unmulched plots. Besides, mulching in 1936 was more effective and it conserved 76·6 tons of water in three feet acre as against 28·8 tons in 1937. For these reasons the difference in yield of mulched and unmulched plots in 1936 was more than in 1937. The difference in the yield of barley in the year 1940-41 and 1941-42 were nearly the same, but in the year 1942-43, when mulching had conserved more moisture, difference in yields were also larger.

Under these conditions it has been observed that mulch during the rainy season is not much effective. Its effect is very much pronounced only after the close of rains in the month of September. After the close of rains one cultivation is sufficient for the formation of soil mulch. Since 3 to 4 in. deep mulch is quite enough to bring about maximum conservation of soil moisture, country plough or any hoe or harrow, which can stir the land to a depth of 3-4 in., can be used for the formation of soil mulch. The results indicate that there is no significant difference between the moisutre content of the plots cultivated with S. T. Harrow or *desi* plough, and therefore a harrow can be used both for the eradication of weeds and mulch formation.

Economics of soil mulch formation

It has been seen that weeds remove about 5 in. of water, and reduce the soil moisture down to 6 ft. depth to its wilting coefficient. This huge amount of water is sufficient to produce about 500 lb. of *bajra* grain (*Pennicetum typhodeum*). It is, therefore, very necessary that the fields may be kept clean of weeds, and for this purpose they should be cultivated occasionally. The cultivation for removing the weeds can also form soil mulch, and consequently no additional expenditure is involved.

Summary

1. A study of the relative effect of soil mulch and weeding on the conservation of moisture under dry farming conditions is presented. The subject being controversial, a thorough investigation was carried out under field conditions, in pots, and in observation plots at the Rohtak Dry Farming Research Station.

2. The results show that soil mulch conserves moisture, and its effectiveness depends on the initial moisture content of the soil. About 33 per cent more moisture is present in the mulched than in the unmulched plots. A correlation between the moisture in the surface 6 in. and the total moisture conserved has been worked out.

3. Capillarity starts from the surface, so does the effect of mulching. Depth to which soil mulch can conserve moisture depends on the rainfall or moisture content of the soil. Generally, significant differences are found in the surface foot.

4. Effect of soil mulch varies with the type of soil. It was more effective on a loam than on fine sandy loam.

5. The results from pot experiment show that soil mulch about 4 in. deep conserved more soil moisture than 2 in. mulch and 6 in. mulch.

6. Weeds remove moisture down to 6-ft. depth, and the water removed by them is equal to 5 in. of rainfall.

7. Use of harrow for conserving soil moisture is recommended. It is as efficient as a plough, but does 3 to 5 times more work.

8. The effect of soil mulch on the germination and yield of different crops has been discussed.

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CONTRIBUTION OF CLAY, SILT AND SAND FRACTIONS AND ORGANIC MATTER OF SOME INDIAN SOILS TOWARDS THEIR BASE EXCHANGE CAPACITIES*

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The base exchange capacity (b.e.c.) of a soil is the sum of the contributions made by its constituents. Of the fractions obtained by mechanical analysis clay has the highest b.e.c. Silt and especially sand fractions have much smaller b.e.c. and the contribution of the latter is small. The gravel fraction also possesses some exchange capacity although negligible compared to that of the others. The organic matter of the soil has generally a b.e.c. higher than the clay. The percentage of organic matter of Indian soils is usually quite low but there are soils whose total exchange capacity is so small that the contribution of the organic matter becomes appreciable.

Turner [1932] calculated from his own data as also from those of Hissink, Oden, Kerr and others the contributions of clay and organic matter to the exchange capacity and obtained statistically significant correlation of the b.e.c. of soil with those of clay and organic matter. Gedroiz [1930] determined the b.e.c. of the soil before and after oxidation with H_2O_2 and indicated the possibility of estimating the b.e.c.'s of the mineral and humus portions of the soil. Anderson and Byers [1931] have followed this procedure. Gedroiz [1930] as also McGeorge [1930] have shown that humus-free soils are affected very little on treatment with H_2O_2 so far as their b.e.c.'s are concerned. Waksman [1938] has given a full account of such measurements. In the present paper*** the contributions of the different fractions and the mineral and organic constituents to the total exchange capacity of some Indian soils have been recorded.

The following soils have been used:

Lab. No.	*Description*
14	Burdwan Farm Soil, Bengal—0-6 in.
25A	Black Cotton soil from Satara, Bombay—0-6 in.
20	Kalyanpur Farm soil, Cawnpur—0-6 in.
10	Suri Farm soil, Bengal—0-6 in.

* The results given in this paper were published in the Annual Report for 1939-40 on the working of the scheme of research into the properties of colloid soil constituents financed by the Imperial Council of Agricultural Research and directed by Prof. J. N. Mukherjee

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*** Results of determination of base exchange capacity of clay or clay *plus* organic matter have shown that their contributions do not fully account for the b.e.c. of the soil. (See Annual Report of the Working of the Scheme of Research into the Properties of Colloid Soil Constituents, 1938-39).

Experimental

Clay, clay *plus* silt and sand (coarse and fine together) were separated by dispersion according to the International soda-method [1933] but excluding the pretreatment with H_2O_2. The gravel fractions were separated only from soils Nos. 20 and 25A. Care was taken to wash the sand and gravel fractions completely free from the finer fractions. Excepting the sand and gravel fractions, whose b.e.c.'s were determined only after oxidation with H_2O_2, each fraction was divided into two portions, one was treated with 6 per cent H_2O_2 while the other was not so treated. The sieved samples were similarly treated. Parker's barium acetate-ammonium chloride method [Parker, 1929] has been used. The amount of organic matter was determined from the loss on oxidation with 6 per cent H_2O_2. The b.e.c. of the silt fraction has been obtained from the difference between those of the silt *plus* clay and of clay alone and is found to be low. It has been obtained as the difference between two larger quantities and hence it is liable to magnified errors.

The results in Table I show that even the coarser fractions of the black cotton soil have an appreciable b.e.c. It is interesting to note that the organic matter of the soils differs widely as regards its b.e.c.

Table I

Soil	Percentage of					B.e.c. per 100 gm. oven-dried				
	Clay	Silt	Sand	Gravel	Org. matter in soil	Clay	Silt	Sand	Gravel	Org. matter
Black cotton	56·7	15·0	11·8	16·5	3·6	88·6	4·3	6·8	3·8	353
Kalyanpur	18·7	20·9	47·0	15·0	0·7	54·6	5·7	0·6	0·09	210
Suri	10·5	17·0	..	..	2·4	37·3	4·7	..	..	154
Burdwan	7·7	3·6	..	..	1·0	41·7	2·3	..	..	100

Treatment with 6 per cent H_2O_2 does not completely remove the organic matter [Alexander and Byers, 1932 ; Mitchell, 1932] and it may also effect some change in the nature of the mineral complex. Neglecting these possible objections the b.e.c. of the organic matter in the different mechanical fractions and in the soil has been calculated (Table II). The b.e.c. of the organic matter is of the same order as that found by other investigators. The very low b.e.c. of the organic matter associated with the Burdwan soil and its clay *plus* silt fraction is, however, worthy of notice.

Table II

Soil	Per cent organic matter from loss on oxidation with 6 per cent H_2O_2			B. e. c. in m. e. per 100 gm. organic matter obtained from		
	Clay	Clay+silt	Soil	Clay	Clay+silt	Soil
Black cotton	1·9	4·38	2·5	463	255	353
Kalyanpur	2·87	0·93	0·7	318	232	210
Burdwan	0	3·44	2·4	..	77	100
Suri	2·25	1·2	1·0	375	223	154

The equivalent weights of the organic substances responsible for base exchange properties and of clay and silt are given in Table III. Previous investigators have observed values from 150 to 800 for the organic matter of the soil and humic acids obtained from various sources. Hissink [1924-25] found the equivalent weight of clay to vary from 1033 to 2061 and Turner [1932] gave values of 4100 ±600 for clay and of the order of 20,000 for silt.

TABLE III

Soil	Equivalent clay	Weight of silt	Equivalent weight of organic matter from		
			Clay	Clay+silt	Soil
Black cotton	1129	23256	216	385	284
Kalyanpur	1831	17540	314	431	476
Burdwan	2400	21300	..	1304	1000
Suri	2681	43400	267	450	649

Wide variations in the equivalent weight have been recorded. The fractions contain particles of different sizes and the finer fractions are expected to show smaller equivalent weights if base exchange capacity is restricted to the interface. While this is possible for the inorganic constituents it is interesting to find that the same appears to be also true of the organic matter (Table II). Thus the organic matter present in the clay fraction has definitely a higher b.e.c. than that present in the soil or the silt.

The contributions of each of these fractions towards the b.e.c. of the soil are given in Table IV. Their sum has been compared with the observed b.e.c. of the soil. The agreement is fairly satisfactory and implies that the process of separation does not alter the base exchange properties of the constituents to any large extent and that the manner of estimation of the organic constituent is not altogether unsatisfactory.

TABLE IV

Soil	Contribution of				Total (calc.)	b. e. c. of soil (observed)
	Clay	Silt	Sand	Org. matter		
Black cotton	50·23	0·70	0·80	8·7	60·40	56·0
Kalyanpur	10·20	1·20	0·30	1·4	13·1	11·8
Suri	3·9	0·8	..	1·5	6·2	5·6
Burdwan	3·2	0·1	..	2·4	5·7	6·5

SUMMARY AND CONCLUSION

The base exchange capacity (b.e.c.) of the clay, clay *plus* silt, sand and organic matter of some Indian soils has been determined by the barium acetate-ammonium chloride method of Parker. The clay, clay *plus* silt and sand were obtained as in the mechanical analysis of soils but without pretreatment with hydrogen peroxide. The b.e.c. of each of these fractions (excepting the sand whose b.e.c. was determined after treatment with hydrogen peroxide) was determined both before and after treatment with hydrogen peroxide. From the difference in b.e.c. in the two cases and the percentage loss on ignition, the b.e.c. of organic matter was calculated.

Of the different fractions of the soil, viz. clay, silt, sand and organic matter, clay makes the highest contribution to the total b.e.c. and the organic matter comes next. The percentage of organic matter is very small in the soils studied but its contribution is appreciable by reason of its high b.e.c. The contributions of silt and sand are quite negligible.

The b.e.c. of organic matter has been found to be of the same order as obtained by other investigators. The organic matter associated with clay has a higher b.e.c. than that associated with either silt or soil.

The sum of the contributions made by the different constituents of the soil as determined separately has been found to compare satisfactorily with the b.e.c. of the soil itself.

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COMPARISON OF THE ACID EXTRACTS OF SOME INDIAN SOILS OBTAINED BY DIFFERENT METHODS*

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Analysis of the acid extract of soil is often included in routine soil analysis. It gives some idea of the 'weathering' of soils and is also likely to provide criteria for differentiating them. Several methods are available for the preparation of the extract. Data on the acid extracts of Indian soils are no doubt available but comparison of acid extracts of different soils to be helpful should be done by the same method. The lack of a standardized method considerably detracts from the usefulness of these data for purposes of soil systematics and soil classification [Russell, 1938]. A comparison of the more common methods is, therefore, desirable. The methods used in this work with particulars regarding the concentration of the acid employed, the soil/acid ratio and the time and temperature of extraction, are given in Table I.

Table I

—	Concentration of acid	Soil/acid ratio	Time of extraction	Temperature of extraction
I. Bemmelen-Hissink	25 per cent	25	2 hours	110°C. reflux
II. A. E. A.	Constant boiling HCl (about 22 per cent)	10	1 hour	Gentle boiling in a beaker with a cover disc
III. Sigmond	25 per cent	25	1 hour	110°C. reflux
V. Tri-acid digestion . . .	Concentrated acids mixed in certain proportions	30	Digested until fumes of SO_3 cease to be evolved	

The soils used have been described in Table II.

Table II

Description of soils

Lab. No.	Soil	Carbonate per cent	*p*H
20	Kalyanpur farm soil 0-6 in.	0·54	7·3
46	Padegaon 'B' type 0-12 in.	5·7	8·6
49	Sakrand saline soil	...	...
49A	Sakrand saline soil	...	...
55	Highland acid soil from Oating, Assam, 0-6 in.	*Nil.*	5·0
63	Madras, Laterite	...	...

The two saline soils (Nos. 49 and 49A) included in group A have been studied using methods I, II and III and in the case of the other four soils belonging to group B, methods I, II and IV were employed. The results are given in Tables III and IV.

In group A, the percentages of material soluble in HCl appear to be in the order I>II=III. In group B the order is IV>II. The time of interaction of the soil with HCl in the first three methods is in the order I>II=III. Although the time of interaction in II and III is the same, the soil-acid mixture is put under reflux in the latter whereas in the former the soil is gently boiled with acid in a beaker. Moreover the soil/acid ratio (Table I) is different in the two cases.

* The results given in this paper were published in the Annual Report for 1940-41 on the working of a scheme of research into the properties of colloid soil constituents financed by the Imperial Council of Agricultural Research and directed by Prof. J N. Mukherjee

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TABLE III
Group A
Comparison of different methods of HCl extract of soils
(Values calculated per 100 gm. of air-dry soil)

Sakrand soil Lab. No.	Moisture	Loss on ignition	CO_2	Acid insoluble	Soluble SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CaO	MgO	K_2O	Na_2O	Total	HCl soluble material
						A. E. A. methods								
49	2·8	1·4	4·6	72·3	0·27	7·1	4·1	0·20	4·7	0·21	1·91	0·59	100·2	27·9
49A	5·5	1·8	4·5	65·4	0·30	7·9	3·9	0·13	4·6	0·18	1·99	1·17	97·4	32·0
						International method								
49	2·8	1·4	4·6	70·7	0·22	7·0	4·1	0·19	4·8	0·19	2·1	0·73	98·9	28·2
49A	5·5	1·8	4·5	64·3	0·25	8·4	4·1	0·15	4·4	0·15	2·3	1·23	97·1	32·8
						Sigmond method								
49	2·8	1·4	4·6	72·7	0·27	6·9	4·1	0·17	4·4	0·22	2·2	0·69	100·5	27·8
49A	5·5	1·8	4·5	67·5	0·25	8·0	3·9	0·12	4·2	0·17	2·1	1·33	99·3	31·8

TABLE IV
Group B
Comparison of different methods of acid extract of soils
(Results expressed per 100 gm. of air-dry soil)

Lab. No.	Soil	Moisture	Loss on ignition	CO_2	Acid soluble	Soluble SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CaO	MgO	K_2O	Na_2O	Total	Alkali* soluble SiO_2	HCl soluble material
							A. E. A. method									
46	Padegaon 'B' type	7·7	9·1	4·2	44·6	1·05	15·8	6·7	0·17	7·1	1·6	0·5	0·29	98·8	30·4	54·2
20	Kalyanpur	0·9	1·0	0·4	82·1	0·37	5·9	4·3	0·14	0·77	0·35	1·0	0·19	97·4	13·8	15·3
55	Oating	1·8	3·2	*Nil.*	88·5	0·57	3·4	2·9	0·07	0·08	trace	0·24	0·14	100·8	24·0	12·3
63	Madras Laterite	1·9	1·9	*Nil.*	87·5	0·09	3·6	2·6	0·06	0·35	trace	0·48	0·25	98·7	15·1	11·2
							International method									
46	Padegaon 'B' type	7·7	9·1	4·2	43·6	1·03	15·5	6·7	0·14	7·7	1·3	0·51	0·27	97·6	31·9	54·0
20	Kalyanpur	0·9	1·0	0·4	81·3	0·37	5·7	4·7	0·14	0·85	0·33	1·0	0·16	97·4	12·7	16·1
55	Oating	1·8	3·2	*Nil.*	87·3	0·53	3·7	3·0	0·06	0·07	trace	0·28	0·10	100·1	25·1	12·8
63	Madras Laterite	1·9	1·9	*Nil.*	86·6	0·1	3·9	2·9	0·05	0·36	trace	0·5	0·19	98·5	16·6	11·9
							Tri-acid digestion method									
46	Padegaon 'B' type	7·7	9·1	4·2	42·7	...	16·4	7·4	0·20	9·1	1·9	1·0	0·35	100·1	27·8	57·4
20	Kalyanpur	0·0	1·0	0·4	77·4	...	8·1	5·4	0·18	1·3	0·56	1·7	0·25	97·3	12·2	19·4
55	Oating	1·8	3·2	*Nil.*	84·1	...	6·5	3·2	n.d.	0·1	trace	0·6	0·18	99·7	19·1	15·6
63	Madras Laterite	1·9	1·9	*Nil.*	84·5	...	5·4	3·0	n.d.	0·4	trace	0·8	0·21	98·1	12·8	13·6

* 5 per cent KOH is used in A. E. A. and International methods
2 per cent NaOH is used in Tri-acid digestion method

The results show that of the four methods which considerably differ in the process of extraction I, II and III give almost the same composition of the acid extract with the different soils. The tri-acid digestion method (IV), however, gives definitely higher values for Al_2O_3, Fe_2O_3, CaO, MgO and K_2O. This method thus appears to be more drastic than the other three. It may also be possible that some of the silicate B is dissoved by the hot concentrated sulphuric acid in the tri-acid treatment. Again it should be noted from the results given in Table IV that the alkali soluble or combined SiO_2 in I and II, where 5 per cent KOH is used for the dissolution of separated silicic acid, are practically the same but in the tri-acid digestion method, where 2 per cent NaOH is used, the value is low. In the tri-acid digestion, where the total amount of the acid soluble material is higher than in others, the combined SiO_2 should consequently be higher. It is therefore possible that either 2 per cent NaOH is not strong enough to dissolve the separated silicic acid or 5 per cent KOH is too strong and to a certain degree attacks the acid insoluble portion.

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CYTOLOGICAL INVESTIGATIONS ON HEXAPLOID COTTONS

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(Received for publication on 25 June 1943)

(With 14 text-figures)

Hexaploid cottons with 78 somatic chromosomes have been obtained by somatically doubling the chromosome numbers of the sterile triploid hybrids ($2n=39$) of (*a*) cultivated Asiatics and cultivated Americans, (*b*) wild Americans and cultivated Americans, (*c*) cultivated Americans and *G. Sturtii*, and (*d*) cultivated Americans and *G. anomalum*, Wawra and Peyr [Amin, 1940, 1, 2; 1941, 1, 2; Beasley, 1940, 1942; Harland, 1940; Iyengar, 1942]. The hexaploids thus obtained showed much better fertility as compared with the corresponding triploids which are generally highly sterile. The above authors have also given a general morphological account of the hexaploids built by them. Cytologically some information has also been obtained regarding the chromosome conjugation in some of the above hexaploids [Beasley, 1942; Amin, 1941, 1; Iyengar, 1942]. In the present paper chromosome conjugation of eight hexaploids has been dealt with. As no information is available so far about the chromosome numbers of the progenies of the hexaploids this aspect has also been studied.

Material and methods

At the Agricultural Research Station, Surat, a number of hexaploids were obtained by treating the shoots of the triploid hybrids of cotton with an aqueous solution of colchicine, during the season 1940, 1941 and 1942 [Amin, 1941, 1, 2]. The eight hexaploids selected for cytological study have the parentage shown in the statement given on the next page.

Flower buds were fixed either in acetic alcohol or in carnoy and the pollen mother cells were examined by iron-acetocarmine smear method. The slides were temporarily sealed for examination. Root tips were collected from the plants raised in pots and fixed in 'Craf' [Randolph, 1935]. Prior to fixation, the root tips were dipped for a moment in Carnoy. They were then sectioned by the usual paraffin method and stained either with gentian violet or crystal violet. All drawings were made with the aid of a camera lucida, drawn at bench level using a 1·8 achromatic objective and X15 and X20 compensating oculars.

Meiosis in the hexaploid involving cultivated Asiatics and cultivated Americans

2 [(AD) A]

Hexaploid S. 28-1. 2 [(AD)1 A1]. The triploid shoot of this hybrid which has the formula (AD)1· A1, showed the following conjugation of chromosomes at metaphse I (Table I). Fig. 1 shows 14 I+9 II+1 III+ 1 IV at metaphase I.

Hexaploid	*Parentage*	
	Species with n=*13 chromosomes*	*Species with* n=*26 chromosomes (Cultivated Americans)*
S. 28—1	*G. herbaceum* L, var frutescens-Delile (Surat 1027 A. L. F.) 2 A1*	*G. hirsutum* L (Coimbatore 2) .... 2 (AD)1
S. 31—1	Ditto	*G. barbadense* L (Sea Island) .... 2 (AD)2
S. 34—1	Ditto	Ditto ....
39—1	*G. arboreum* L 2 A2	*G. hirsutum* L (Uganda 4) .... 2 (AD)1
Wild American cultivated American.	*G. thurberi* Tod 2 D1	*G. barbadense* L (Boss III-16) .... 2 (AD)2
Ditto	*G. armourianum* Kearney 2 D2	*G. barbadense* L (Sea Island) .... 2 (AD)2
Wild African cultivated American	*G. anomalum* Wawra and Peyr 2 B1	*G. hirsutum* L (Coimbatore 2) .... 2 (AD)I
Ditto	Ditto	*G. barbadense* L (Sind Sea island 2-4) .... 2 (AD)2

*Genom symbols A1, A2, (AD) 1, etc. used in this paper are after Beasley [1940,1942]

TABLE I

Chromosome conjugation in triploid S28-1

Chromosome configurations				Number of Pollen mother cells
Univalents	Bivalents	Trivalents	Quadrivalents	
13	13	...	...	2
13	11	...	1	3
13	9	...	2	3
13	10	2	...	3
14	9	1	1	1
14	11	1	...	1
15	12	...	...	3
15	10	0	1	1
16	10	1	...	1
12	12	1	...	2
12	9	3	...	1
11	11	2	...	1
Total 294	236	16	11	22
Mean . 13·36	10·73	0·73	0·50	

The above analysis is in agreement with the data of Webber [1935, 1939] and of Beasley [1942] but differs from the data of Skovsted [1934]. According to the latter, 13 I and 13 II are not seen, while the analysis of Webber [1935, 1939] shows that this combination forms the mode. But Beasley's [1942] results and the present analysis show that such a combination takes place only rarely. According to Skovsted [1934], univalents are always 13 and above. But Webber's [1935, 1939], Beasley's [1942] and the data on hand show that occasionally univalents less than 13 are often formed. Skovsted [1934] gets very frequently pentavalents and hexavalents. Such higher multivalents are found rarely in Beasley's [1942] and are absent in Webber's [1935, 1939] and in the present data. These indicate that chromosome conjugation in the allotriploid under study is influenced also by other factors than homology. The means of the chromosome conjugation of such allotriploids studied by the workers quoted above are given in Table II.

TABLE II

Mean chromosome conjugation in the triploid hybrids between American and Asiatic cottons

Author	Mean chromosome conjugation					
	Univalents	Bivalents	Trivalents	Quadrivalents	Pentavalents	Hexavalents
Skovsted [1934] . .	14·43	8·43	1·03	0·63	0·25	0·51
Webber [1935] . .	13·71	11·94	...	0·35	...	...
———[1939] . .	13·22	12·74	0·10	...	...	...
Beasley [1942] . .	13·03	9·92	0·10	1·36	0·05	0·03
Present data . .	13·36	10·73	0·73	0·05	...	...

It is seen that there is a great uniformity in the values so far as the univalents are concerned. According to Skovsted [1934] and others, the 13 univalents probably represent the wild American component of the cultivated American parent and the bivalents and multivalents represent the two Asiatic sets present in the allotriploid. The differences in the mean number of bivalents and multivalents seen in the above table indicate different degrees of autosyndesis.

FIG. 1

FIG. 2

FIG. 3

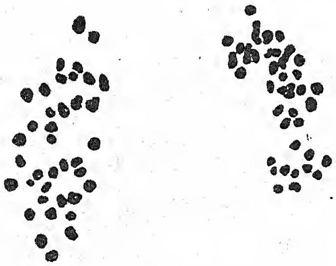

FIG. 4

FIG. 5

FIG. 6

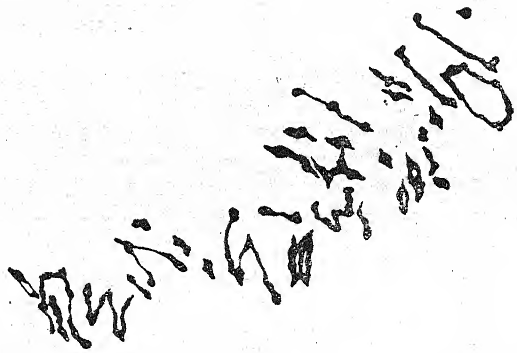

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 1. Metaphase I in triploid S. 28-1 showing 14 I+19 II+1 III+1 IV
FIG. 2. Metaphase I in hexaploid S. 28-1 showing 3 I+30 II+1 III+3 IV
FIG. 3. Metaphase II in hexaploid S. 28-1 showing 39 chromosomes in each plate
FIG. 4. Metaphase II in hexaploid S. 31-1 showing 40 chromosomes in one plate and 38 in the other
FIG. 5. Metaphase I in hexaploid S. 31-1 showing 40 bodies (41+34II+2III)
FIG. 6. Metaphase I in hexaploid S. 34-1 showing 3 I+31 II+3 III+1 IV
FIG. 7. Metaphase I in hexaploid H. 39-1 showing 4 I+20 II+3 III+5 IV+1 V
FIG. 8. Metaphase I in the triploid *G, barbadense* (Boss III-16) ×*G. thurberi* F. 1. showing 13 I and 13 II
FIG. 9. Metaphase I in the hexaploid *G. barbadense* (Boss III-16). ×*G. thurberi* F. 1. showing 35 II and 2 IV
FIG. 10. Metaphase I in the hexaploid *G. barbadense* (Bangalore Sea Island) ×*G. armourianum* showing 3I+30 II+1 III+3 IV

N. B. **All drawings are made from temporary acetocarmine smears (× 1187)**

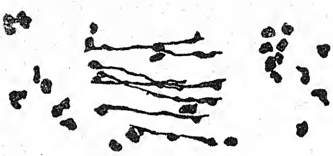

FIG. 11

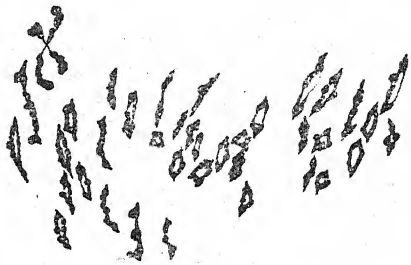

FIG. 12

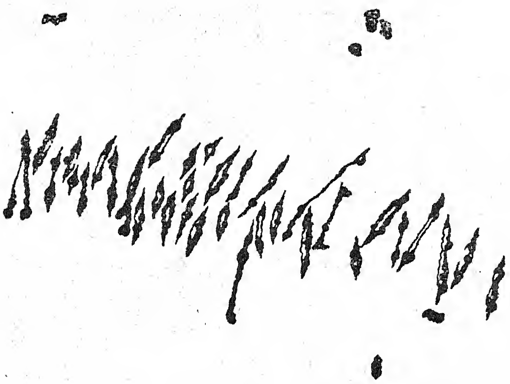

FIG. 13

FIG. 14

FIG. 11. Metaphase I in the triploid *G. barbadense* (Sind Sea Island 2-4) × *G. anomalum* F. 1. showing 25 and 7II

FIG. 12. Metaphase I in the hexaploid *G. barbadense* (Sind Sea Island 2-4) × *G. anomalum* showing 39 II

FIG. 13. Metaphase I in the haxaploid *G. hirsutum* (Coimbatore 2) × *G. anomalum* showing 6 I+33 II+2 III

FIG. 14. Anaphase I in the hexaploid *G. barbadense* (Sind Sea Island 2-4) × *G. anomalum* showing three bridges, one is broken

N. B. All drawings are made from temporary acetocarmine smears (× 1187)

Chromosome conjugation of the hexaploid S. 28-1 is given in Table III. Fig. 2 shows the chromosome conjugation at metaphase I. In the analysis, it is seen that the univalents are very few and range from 1 to 3. The proportion of bivalents is high. Trivalents and quadrivalents are met with in all the cells and often hexavalents are seen. Though the mean number of quadrivalents is low (3·58), in individual cells their number is high (range 0-7). Beasley [1942] figures a metaphse I, which shows many bivalents and some univalents and multivalents. As no analysis is given, his results may be similar to the data presented in the paper. But one significant point has been mentioned by him which is in agreement with the data on hand. On the assumption that the chromosome formula of the hexaploid analysed by him and by the author is 2 [(AD) 1 A1], the four A sets should form quadrivalents on the basis of homology. One should expect 13 II and 13 IV. But the number of quadrivalents as mentioned above and as reported by Beasley [1942] is much lower on the whole. Beasley states, " the amount of chromosome differentiation evidenced in the triploid has considerable influence on chromosome pairing, for the number of quadrivalents is much less than would be expected if four identical sets were present. Associations of more than four chromosomes not structurally alike will sometimes pair even though completely homologous chromosomes are present ; this is known, however, from pairing in natural species."

Anaphase I was clean in many cells. Lagging univalents were however noticed in many cases. In the figures analysed by Beasley [1942] lagging chromosomes, bridges and fragments are common, but the number of these in a given anaphase is usually one or two. According to him counts of two anaphase cells showed 40/38 and 40/40 distribution.

TABLE III

Chromosome conjugation in the hexaploid involving cultivated American and Asiatic cottons

Chromosome configurations						Hexaploids				Total number of P.M.C.
Univalents	Bivalents	Trivalonts	Quadri-valents	Penta-valents	Hexa-valents	S. 28-1	S. 31-1	S. 34-1	39-1	
..	19	..	4	..	4	..	..	..	1	1
4	20	3	5	1	..	..	..	..	1	1
..	22	..	7	..	1	1	..	..	..	1
3	24	1	6	..	..	1	..	..	..	1
2	24	..	7	..	..	1	..	..	..	1
..	25	..	7	..	..	2	..	..	..	2
1	25	1	6	..	..	1	..	..	..	1
..	26	..	5	..	1	1	..	..	..	1
..	27	..	6	..	..	1	..	..	..	1
1	27	5	2	..	..	1	..	..	..	1
..	28	2	4	..	..	1	..	..	..	1
2	28	..	5	..	..	1	..	..	..	1
3	28	1	1	..	2	..	..	..	1	1
3	28	1	4	..	..	1	..	..	..	1
3	30	1	3	..	..	1	..	..	..	1
7	30	1	2	..	..	1	..	..	..	1
1	31	1	3	..	..	..	..	..	1	1
3	31	3	1	..	..	..	..	1	..	1
2	32	..	3	..	..	1	..	..	..	1
..	32	2	2	..	..	2	..	1	..	3
1	32	1	1	..	1	..	..	..	2	2
1	33	1	2	..	..	..	..	..	2	2
..	33	..	3	..	..	1	1	..	..	2
6	33	2	..	..	..	..	1	..	..	1
2	33	2	1	..	..	1	..	..	..	1
2	33	..	1	..	1	1	..	..	..	1
4	34	2	..	..	..	..	3	..	..	3
2	34	..	2	..	..	..	1	..	..	1
3	34	1	1	..	..	..		1	..	1
..	35	..	2	..	..	1	..	..	..	1
5	35	1	..	..	..	..	1	..	..	1
1	35	1	1	..	..	1	..	..	..	1
..	36	2	..	..	..	..	1	1	..	2
1	37	1	..	..	..	2	..	3	..	5
..	37	..	1	..	..	..	..	1	..	1
G. total 77	1490	52	115	1	11	24	8	8	8	48
G. mean 1·60	31·04	1·08	2·40	0·02	0·23					

TABLE III—*contd.*

		Hexaploids			
		S. 28-1	S. 31-1	S. 34-1	39-1
Totals of	Univalents	31	25	9	12
	Bivalents	708	273	281	228
	Trivalents	21	11	11	9
	Quadrivalents	86	5	5	19
	Pentavalents	...	...	...	1
	Hexavalents	3	...	...	8
Means of	Univalents	1·29	3·13	1·13	1·50
	Bivalents	29·50	34·13	35·13	28·50
	Trivalents	0·88	1·38	1·38	1·13
	Quadrivalents	3·58	0·63	0·63	2·38
	Pentavalents	...	...	...	0·13
	Hexavalents	0·13	...	...	1·00

Metaphase II, in the hexaploids under study, showed plates where chromosomes ranged from 34 to 42 (Figs. 3 and 4). Bridges were also noticed at this stage. The resulting sporads showed abnormalities. Of the 60 sporads counted, in 30 cases the sporads had 4 cells of more or less equal size. In the rest they were of variable sizes. Dyads were fairly frequent.

Table III also gives the chromosome conjugation in the hexaploids S. 31-1, S. 34-1 and 39-1. Figs. 5, 6 and 7 show the chromosome conjugation at metaphase I.

MEIOSIS IN THE HEXAPLOIDS INVOLVING WILD AMERICANS AND CULTIVATED AMERICANS 2 [(AD)2 D1)] AND 2 [(AD) 2D2]

The parents involved in the hexaploids under study have been previously described and they have the general formula 2 [(AD) D]. The

triploid hybrid which has a chromosome formula (AD)2 D1, sets bolls occasionally, but the hexaploid is much more fertile. Webber [1939] also obtained some setting in the triploid hybrid. Table IV gives the chromosome conjugation of the triploid hybrid under study.

TABLE IV

Chromosome conjugation in the triploid hybrid between G. berbadense *and* G. thurberi

Chromosome configurations			Number of p.m.c.	
Univalents	Bivalents	Trivalents		
13	13	..	20	
15	12	..	5	
17	11	..	1	
12	12	1	2	
11	11	2	1	
11	14	..	1	
398	380	4	30	Total
13·27	12·67	0·13		Mean

Fig. 8 shows 13 univalents and 13 bivalents at metaphase I. The above analysis is in agreement with the data presented by Webber [1939] for the triploid hybrid *G. hirsutum* × *G. thurberi*, F. 1, where the mean conjugation was 13·06 I+12·07 II+0·18 III. The mode obtained by him is also 13 I and 13 II. The means of the conjugations of Skovsted's [1937] triploid hybrids between *G. barbadense* × *G. thurberi* and *G. hirsutum* and *G. thurberi* which are somewhat fertile, are 12·7 I +12·4 II+0·5 III and 13·5 I+12·45 II+0·2 III respectively. There is a close agreement in all the analyses. A similar result is also obtained by Beasley [1942].

The hexaploids 2 [$(AD)_2 D_1$] obtained by doubling the chromosome numbers of the triploids $(AD)_2D_1$, shows bodies ranging from 30 to 39 at metaphse I. Fig. 9 shows a metaphse I with 35 II and 2 IV. Table V gives the analysis of chromosome conjugation at metaphse I.

TABLE V

Chromosome conjugation in the hexaploid involving G. barbadense *and* G. thurberi

Chromosome configurations						Number of p.m.c.
Univalents	Bivalents	Trivalents	Quadrivalents	Pentavalents	Hexavalents	
1	25	1	6	...	...	2
3	26	1	5	...	...	1
...	27	...	6	...	...	1
...	29	...	5	...	...	1
...	30	...	3	...	1	1
1	31	1	3	...	...	1
1	33	1	2	...	...	1
...	33	...	3	...	...	1
...	34	2	1	...	...	1
1	35	1	1	...	...	1
...	35	...	2	...	...	3
3	36	1	...	...	...	1
...	37	...	1	...	...	1
1	37	1	...	...	...	1
2	38	...	...	...	...	2
...	39	...	...	...	...	5
16	815	10	48	...	1	24
0·67	33·96	0·42	2·00	...	0·04	

Compared with the hexaploids dealt in the earlier part of the paper, meiosis in the hexaploid under study appears to be a bit more regular. The range of quadrivalents is from 0 to 6 but the mean number of quadrivalents is much less than expected.

In many cells, no laggards were noticed at anaphse I and anaphse II. In some cells bridges were noticed at anaphase I. In some anaphases only fragments were noticed.

In the hexaploid involving cultivated American and *G. armourianum*, 2 [$(AD)_2D_2$], the chromosome conjugation is more or less similar to the hexaploid dealt above. Univalents are commonly seen (1 or 2) in most of the cells examined. Trivalents and quadrivalents are also met with Table VI gives the analysis of the chromosome conjugation in this hexaploid and Fig. 10 shows a typical conjugation at metaphse I.

Beasley [1942] records in the hexaploid of *G. hirsutum* × *G. harknesii*, univalents, trivalents associations of three or four chromosomes or a combination of the three and at anaphase I one or more bridges. He finds a more normal chromsome behaviour during the meiosis of this hexaploid than the hexploid 2 [(AD)1 A1], of American-26 and Asiatic-13 chromosome species.

MEIOSIS IN THE HEXAPLOID INVOLVING WILD AFRICAN *G. ANOMALUM* WAWRA AND PEYR, AND CULTIVATED AMERICAN. 2 [(AD) B]

In the triploids of the constitution (AD)B, the data of Webber [1939] and of Skovsted [1937] do not agree. The former gets 18·12 I+10·32 II + 0·08 III in one hybrid and 17·18 I+10·48 II+0·11 III in another hybrid, while the latter gets 33·1 I and 2·6 II. Beasley [1942] on the other hand gets 8·9 II in his analysis. The author of the present paper finds the following averages for the two hybrids analysed.

G. hirsutum (S. G. 23/8×*G. anomalum* F. 1. 227·4 I+52 II+0·17 III.

G. barbadense (Sind S. I. 2-4) $\times$ *G. anomalum F.* 1—$25 \cdot 4\ \mathrm{I} + 6 \cdot 4\ \mathrm{II} + 0 \cdot 2\ \mathrm{III} + 0 \cdot 05\ \mathrm{IV}$.
Thus, the triploids of this constitution show high variability in chromosome conjugation. Fig. 11 shows 25 I and 7 II in the triploid hybrid *G. barbadense* (S. I. 2-4) $\times$ *G. anomalum.*

TABLE VI

Chromosome conjugation in the hexaploid involving G. barbadense *and* G. armorianum

Chromosome configurations						Number of p.m.c.
Univalents	Bivalents	Trivalents	Quadrivalents	Pentavalants	Hexavalents	
3	23	2	3	1	1	1
...	26	...	5	...	1	1
3	28	1	4	...	...	1
4	29	...	4	...	...	1
7	30	1	2	...	...	1
4	30	2	2	...	...	1
3	30	1	3	...	...	1
5	31	1	2	...	...	1
2	31	2	2	...	...	2
1	31	1	3	...	...	1
2	32	...	3	...	...	1
...	33	...	3	...	...	1
1	33	1	2	...	...	1
3	34	1	1	...	...	1
2	34	...	2	...	...	1
1	34	3	...	...	...	1
5	35	1	...	...	...	2
...	35	...	2	...	...	1
1	35	1	1	...	...	2
3	36	1	...	...	...	1
4	37	...	...	...	...	1
1	37	1	...	...	...	1
...	37	...	1	...	...	2
2	38	...	...	...	...	1
Total . 65	917	24	49	1	2	28
Means 2·32	32·75	0·86	1·75	0·02	0·04	

In Table VII the analyses of the two hexaploids of the constitution under consideration are given. As in the other hexaploids dealt in the earlier part of the paper, configurations ranging from univalents to octovalents were seen. But on an average the number of bivalents is rather more in this type of hexaploid. Figs. 12 and 13 show chromosome conjugation at metaphse I in the two hexaploids. Fig. 14 shows three bridges at anaphse I in the hexaploid (S. I. 2-4 $\times$ *G. anomalum*). Of these one is broken.

According to Beasley [1942] meiosis in the hexaploid *G. hirsutum* $\times$ *G. anomalum* was nearer normal in chromosome behaviour than any of the induced polyploids studied. In about half of the pollen mother cells at metaphse I, no irregularities were observed. In others, univalents were the most common irregularity and more rarely multivalents were present. Some times one or more bridges were present.

CHROMOSOME NUMBERS OF THE PROGENIES OF THE HEXAPLOIDS

Tables VIII and IX give the chromosome distribution of the progenies of various hexaploids studied. It is seen that most of the plants have 78 chromosomes, indicating that in the hexaploids, gametes with 39 chromosomes seem to function most. A more or less similar constancy of number was seen in the progeny of five plants of an octoploid obtained by doubling the chromosome numbers of a hybrid between *G. hirsutum* (U. 4) $\times$ *G. barbadense* (Giza 7), which gave numbers round about 104. The chromosome number of one hybrid obtained by crossing the octoploid (*G. hirsutum*—U. 4 $\times$ *G. barbadense*—Ashmouni) and the hexaploid S. 28-1 gave about 91 chromosomes. Hexaploid S. 28-1, on crossing with *G. armourianum* gave plants mostly with 52 chromosomes. The chromosome conjugation of a tetraploid thus obtained showed a mean value of $2 \cdot 35\ \mathrm{I} + 24 \cdot 3\ \mathrm{II} + 0 \cdot 35\ \mathrm{III}$. In many pollen mother cells 26 II were seen. The plant was found to be fertile. The above points indicate that gametes with 39 chromosomes seem to function most in the hexaploids under study and that some of the gametes having 39 chromosomes have two sets of Asiatic and one set of wild American chromosomes. The production of such a synthetic fertile tetraploid further supports Skovsted's [1934] allopolyploid origin of the cultivated American cottons.

DISCUSSION

In cotton, hexaploids can arise by at least two methods. Method number I is by doubling the somatic chromosome number of allotriploids as reported in the earlier part of the paper. They may contain the following sets : (*a*) two Asiatics and one wild American, (*b*) two wild Americans and one Asiatic, (*c*) one Asiatic, one wild American and one Australian (*G. sturtii*), (*d*) one Asiatic, one wild American and one African (*G. anomalum*). The chromosome formulae of the hexaploids are as under.

(*a*) 2 [(AD) A] . . Contains 4 A and 2 D

(*b*) 2 [(AD) D] . . Contains 2 A and 4 D

(*c*) 2 [(AD) C1] . Contains 2 A, 2 D and 2 C1

(*d*) 2 [(AD) B1]. . Contains 2 A, 2 D and 2 B1

TABLE VII

Chromosome conjugation in the hexaploid involving cultivated Americans and G. anomalum

Chromosome configurations								Hexaploids		Total number of p.m.c.
Univalents	Bivalents	Trivalents	Quadrivalents	Pentavalents	Hexavalents	Septavalents	Octovalents	*G. hirsutum* × *G. anomalum* *No. of p.m.c.*	*G. barbadense* × *G. anomalum* *No. of p.m.c.*	
7	30	1	2	..	..	..	..	1	..	1
3	32	1	2	..	..	..	..	1	..	1
6	32	..	2	..	..	..	..	1	1	2
7	32	1	1	..	..	..	..	1	..	1
4	33	..	2	..	..	..	..	1	..	1
5	33	1	1	..	..	..	..	2	..	2
6	33	2	..	..	..	..	..	1	..	1
2	34	..	2	..	..	..	..	1	1	2
..	35	1	..	1	..	..	..	1	..	1
..	35	..	..	..	..	..	1	..	1	1
1	35	1	1	..	..	..	..	1	1	2
2	35	2	..	..	..	..	..	..	1	1
4	35	..	1	..	..	..	..	..	1	1
1	36	..	..	1	..	..	..	1	..	1
2	36	..	1	..	..	..	..	2	3	5
3	36	1	..	..	..	..	..	3	1	4
6	36	..	..	..	..	..	..	2	..	2
..	37	..	1	..	..	..	..	2	1	3
1	37	1	..	..	..	..	..	3	2	5
4	37	..	..	..	..	..	..	2	..	2
2	38	..	..	..	..	..	..	2	4	6
..	39	..	..	..	..	..	..	2	3	5
87	1063	15	18	2	..	..	..	30	...	..
34	730	6	10	..	..	..	1	..	20	..
121	1793	21	28	2	..	..	1	..		50

Mean conjugations

Hexaploid *G. hirsutum* × *G. anomalum* 2·90 I + 35·43 II + 0·05 III + 0·06 IV + 0·07V

Hexaploid *G. barbadense* × *G. anomalum* 1·70 I + 36·50 II + 0·03 III + 0·05 IV + 0 V + 0VI + VII + 0·05 VIII

Mean of 50 cells

2·42 I + 35·86 II + 0·42 III + 0·56 IV + 0·04 V + 0·00 VI + 0·00 VII + 0·02 VIII

In the present paper, chromosome conjugation at metaphase I has been studied for the hexaploid types (*a*), (*b*) and (*d*). In the types (*a*) and (*b*), since there are four A's or four D's, quadrivalents are to be expected. Since in the triploids of the constitution (AD) A, multivalents higher than trivalents are seen, the chromosome behaviour of the derived hexaploid may become more complicated by the formation of complicated multivalents. On the other hand, in the triploids of the constitution (AD) D, chromosome pairing at metaphase I shows predominantly 13 I and 13 II. The hexaploids derived from such triploids may show much less complication in chromosome pairing. The analyses of the two hexaploids have however shown that such differences exist only to a small extent in the number of multivalents (Table X).

In the hexaploids of the groups (*c*) and (*d*), there are three different sets and each set is represented twice. In the corresponding triploids either ADC or ADB, meiosis is highly irregular and shows a highly variable conjugation. In the triploid ADC, univalents predominate during meiosis. Webber [1934, 1935] finds only univalents and bivalents, but Skovsted [1937] reports multivalents and quadrivalents. According to Beasley [1942], 39 bivalents are noticed in the hexaploid 2 [(AD) C1], although usually some chromosomes are in associations of four and two or more univalents may be present. Ordinarily one to three bridges are present at anaphase I in this hexaploid, but sometimes they may be absent. The hexaploid behaviour of the group (*d*) has already been dealt with. It is seen that in these triploid hybrids which show a high irregular conjugation and where univalent

TABLE VIII

Chromosome distribution in the progeny of hexaploid cottons

Hexaploids	Chromosome distribution									Total number of plants
	74	75	76	77	78	79	80	81	82	
S. 28—1	..	..	..	2	12	2	1	..	..	17
G. hirsutum (Co 2) × *G. armouriaum* .	..	..	1	1	8	..	..	2	..	12
G. barbadense (Giza 3 and 7) × *G. armourianum*	1	..	..	..	6	..	..	..	1	8
G. barbadense (Sind S. I 2-4) × *G. anomalum*	..	..	..	..	2	..	..	..	..	2
G. hirsutum (S. G. 23/8) × *G. anomalum*	..	..	..	..	10	..	3	1	..	12
Total .	1	..	1	3	38	2	4	3	1	53

TABLE IX

Chromosome distribution of the F_1 between two hexaploid cottons

Hexaploid parents	Chromosome distribution											Total number of plants
	76	77	78	79	80	81	82	83	84	85	86	
S. 28-1 × S. 31-1	..	..	3	..	..	1	..	..	..	..	..	4
S. 31-1 × S. 28-1	..	..	1	..	..	..	..	..	..	..	..	1
S. 28-1 × S. 34-1	1	..	3	..	..	..	..	..	..	1	..	5
2-1 × S. 28-1	..	..	4	..	..	..	..	..	..	..	..	4
S. 28-1 × [*G. hirsutum* (S. G. 23/8) × *G. anomalum*]	..	1	3	..	2	..	..	..	1	..	..	7
S. 31-1 × [*G. barbadense* (S. I. 2-4) × *G. armourianum*]	..	..	1	..	..	..	..	..	..	..	..	1
[*G. barbadense* (S. I. 2-4) × *G. armourianum*] × S. 28-1	..	..	1	..	..	..	..	..	..	..	..	1
Total . .	1	1	16	..	2	1	..	..	1	1	..	23

predominate, chromosome doubling has restored the balance in chromosome pairing, upset by triploidy, and rendered the sterile plants relatively more fertile.

The second method by which the hexaploids may be produced in cotton is by the fusion of an unreduced gamete from an American cultivated cotton and a 26 chromosome gamete from an allotriploid F_1 hybrid. Such first back cross plants with 78 chromosomes have several types of constitution depending upon the make up of the 26 chromosomes derived from the triploid parent. If we assume that a 26 chromosome gamete derived from the parent triploid hybrid between cultivated Asiatic and cultivated American, has a constitution of AD, then the 78 chromosome plant will have 2 (AD) (AD) and the chromosome conjugation may range from 26 III to 26 II+26 I. Higher multivalents are also to be expected as the A sets are represented three times.

TABLE X

Summary of mean chromosome conjugation in hexaploid cottons

Hexaploids	Mean conjugation								Mean number of associations per pollen mother cell
	Univalents	Bivalents	Trivalents	Quadrivalents	Pentavalents	Hexavalents	Septavalents	Octovalents	
(*i*) Cultivated Asiatic and cultivated American 2[A (AD)]	1·60	31·02	1·08	2·42	0·02	0·23	..	..	36·38±0·42
(*ii*) Wild American and cultivated American 2[D(AD)]	1·56	33·31	0·65	1.87	0·02	0·06	..	..	37·44±0·31
(*iii*) *G. anomalum* (African) and cultivated American 2[B(AD)]	2·42	35·86	0·42	0·56	0·04	..	..	0·02	39·300±·17

Conclusions—Differences between (*i*) and (*ii*) not significant, (*ii*) and (*iii*) significant

SUMMARY

Chromosome conjugation has been studied in four hexaploids involving cultivated Asiatics and cultivated Americans, two hexaploids involving wild Americans and cultivated Americans and two hexaploids involving wild African and cultivated Americans. Conjugation has also been studied in the triploids from which the hexaploids were derived. Though the triploids showed marked variations in conjugation, the hexaploids showed only slight differences.

The progeny behaviour of the several hexaploids studied showed that gametes with 39 chromosomes seem to function most in the parent hexaploids and some of the gametes have the same constitution as the triploid progenitors.

Crosses of hexaploids with suitable diploids gave fertile tetraploids with 52 chromosomes. During meiosis, the chromosomes paired mostly as bivalents. These facts indirectly show that the cultivated American cottons with 52 chromosomes are allopolyploids having two sets of Asiatic and two sets of wild American chromosomes.

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STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

XI. TRENDS IN GROWTH OF NORMAL AND *TIRAK* PLANTS WITH SPECIAL STUDIES ON BOLLS*

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(With nine text-figures)

The Punjab-American cotton plants showing the physiological condition of *tirak* are known to make normal growth up to the fruiting stage, when the leaves either turn yellow or begin to assume drooping position according to the nature of soil conditions that cause *tirak*. It is possible that the internal disorder may be setting in at an earlier date than the date of appearance of external leaf symptoms mentioned above. It was therefore necessary to determine the trends in growth of normal and *tirak* affected plants so that the time when the internal disorder sets in may be determined from the nature of growth curves. It was thereby assumed that any internal metabolic disorder would be reflected either in the relative growth rate, the net assimilation rate, the percentage increase in dry matter, or the percentage distribution of dry matter in the different parts of the plant growing on these types of soils. Though the relative growth rate of cotton plant as well as its net assimilation rate, etc. in Egypt have been determined by Crowther [1934], these determinations for the Punjab-American cotton were necessary on account of the peculiar nature of the *tirak* condition developing in the different types of the soils. Martin, Ballard and Simpson [1923] have done work on the growth of the fruiting parts in cotton plant in America. They found that the first three weeks were very important in the formation of the dry matter in the developing cotton bolls. Balls [1915; 1928] in Egypt has done very exhaustive work on the development and the properties of raw cotton. Afzal and Iyer [1934] have measured the growth of different varieties of cotton plant by means of height measurements; their object was to establish the correlation between growth in extension and the dry matter produced. They employed the method followed by Heath [1932] to find out the relative growth rate and other values. It is, however, realized that the growth in height of the main stem is not a very accurate measure of the dry matter produced by the plant. Height may vary due to so many environmental conditions. The growth of cotton in relation to certain specified conditions had not been studied before. It was, therefore, undertaken to study the growth characteristics of the 4F Punjab-American plant on normal soil and on soils where *tirak* occurred employing the dry weight method.

Investigation

The fields with the following types of soils were selected:

(1) Normal sandy loams, (2) sandy loams with saline sub-soils, (3) light sandy soils with nitrogen deficiency, and (4) light sandy soils with nitrogen deficiency and with sodium clay in the subsoil.

The relative growth rate was determined by the formulae $R.G.R. = \frac{\text{Loge } W_2 - \text{Loge } W_1}{T_2 - T_1}$ and the net assimilation rate by the formulae $N.A.R. = \frac{(W_2 - W_1)(\text{Loge } LL_1 - \text{Loge }_1)}{L_2 - L_1}$ where W_1 and W_2 represent the total dry weight at successive stages of 14 days interval and L_1 and L_2, the dry weight of leaves alone per plant on the same dates [Gregory, 1926].

Five-plant samples from sandy loams and sandy loam with saline sub-soil were taken at fortnightly intervals for dry weight determinations. The choice of plants in all samples was perfectly random. During the early stages of growth more than five plants were taken for each sampling to avoid any sampling error as the dry weight per plant in the beginning was very small. For light sandy soils 25-plant samples were taken at each stage as there was great heterogeneity in the plant population on these types of soils. Fresh and dry weights of the different parts of the plants, viz. roots, stems, leaves and fruiting parts were separately determined and recorded.

The curves for the relative growth rate for plants on the four types of soil are given in Fig. 1 (A, B, C and D). There was a depression in the growth rate on the sandy loams with saline subsoils (Fig. 1B) in the month of August and September.

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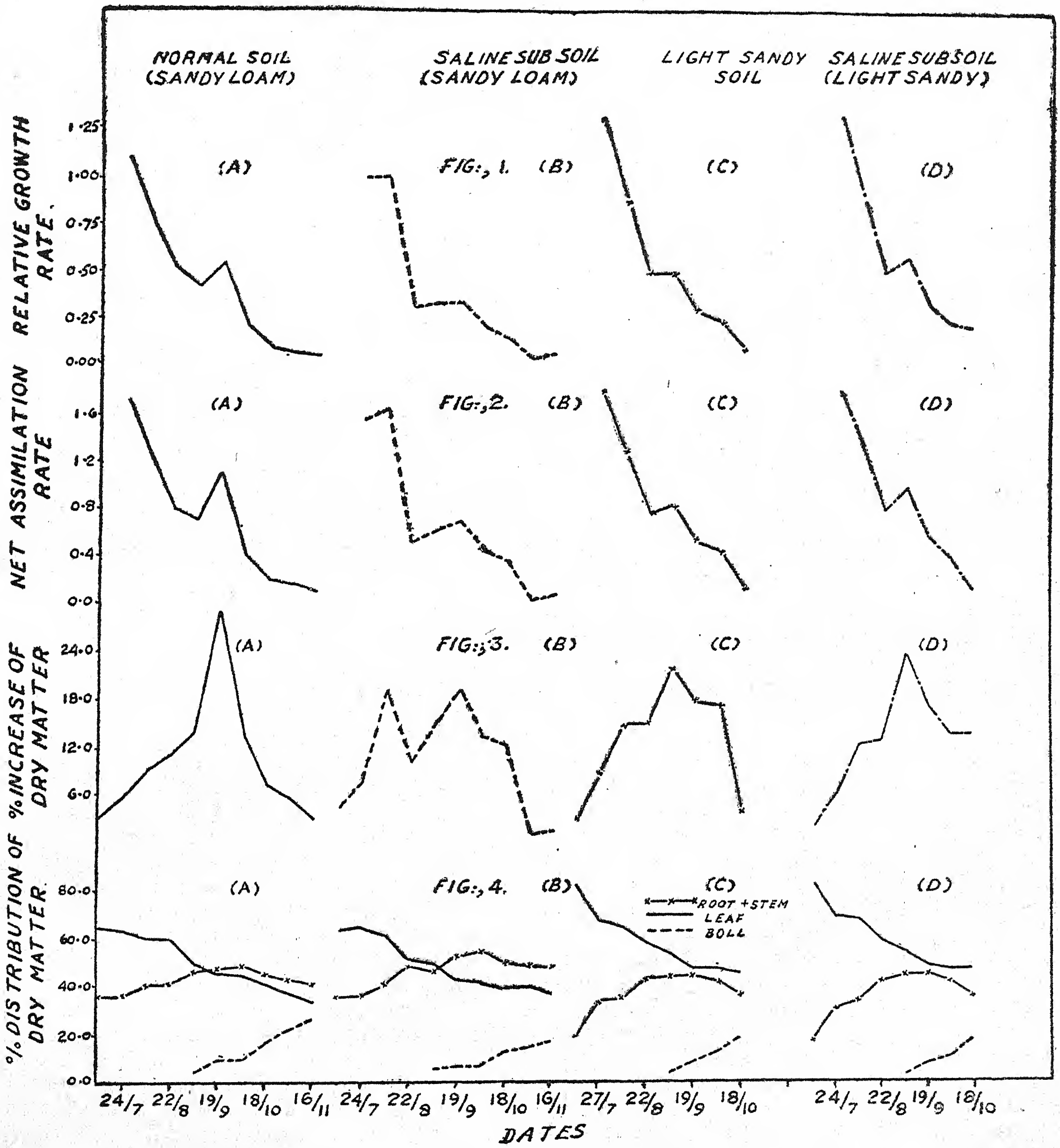
Similar depression was noticed in the net assimilation rate at the same stage (Fig. 2B). It has already been pointed out in a previous paper [Dastur and Sucha Singh, 1942] that during the



FIGS. 1-4. Growth rates of $4F_a$ cotton plant in the normal and *tirak* soils

months of August and September, the crop began to suffer from a deficiency of water in saline subsoils on account of the inability of roots to absorb enough moisture from the saline layers. The development of a water deficit condition in the plant would normally depress the functional activities of the leaves and would have thus inhibitive effects on the growth of the plant. A depression in the relative growth rate was therefore expected.

On light sandy soil deficient in nitrogen there was no such depression visible in the growth rate or the net assimilation rate in the month of August, as the plants on this type of soil did not suffer from a water shortage. The relative growth rate and the net assimilation rate were higher on

these types of soils than on the normal or saline sandy loams in the early stages of the growth (Figs. 1 and 2). This was due to sandy nature of the soil where generally vigorous growth of roots occurred which in turn promoted the growth of shoots and leaves.

The relative growth rate during the months of September and October on normal sandy loams was higher than the relative growth rate on light sandy soils deficient in nitrogen. This may be due to the limiting influence of the nitrogen factor on the latter type of the soil. The plants on the light sandy soils sufferred from nitrogen starvation during the fruiting period and therefore the relative growth rate and the net assimilation rate were also depressed at that stage. Thus water deficit on saline sandy loams, and nitrogen starvation on the light sandy soils produced almost similar effects on the growth of 4F cotton plants.

Percentage increase in dry weight at successive stages. The curves for percentage increase in dry weight are given in Fig. 3 (A, B, C and D) for the four soil types. The curve for sandy loam with saline subsoil was very irregular in shape as compared with the similar curve for normal sandy loam. The percentage increase in dry weight in saline sandy loam soil did not follow the normal trends. The curve for the normal sandy loam showed one marked maximum and the percentage increase in dry matter was highest by the middle of September; while the curve for saline sandy loams showed two maxima of smaller magnitude, one in the beginning of August and the second in the middle af September.

On light sandy soils the maximum percentage increase in dry matter occurred a fortnight earlier, i.e. about the beginning of September as compared with the maxima reached on both types of sandy loams. Greater increases in percentage dry weight were also found to occur in the early stages of the growth on light sandy soil than on sandy loams. This difference may be attributed to the higher relative growth rate on light sandy soils in the early stages caused by better development of root system. The curve for light sandy soil with sodium clay in the subsoil was similar to that of the light sandy soil with normal subsoil (Fig. 3, C and D).

Thus the relative growth rate, the net assimilation rate and percentage increase in dry weights in the early stages were higher in the light sandy soils than on the normal or saline sandy loams. This difference was mainly due to the differences in the physical properties of the soil. The light sandy soils contain more sand than sandy loams and the greater amount of sand promotes the root growth and consequently the growth of shoots and leaves. But the higher rate of increase in dry matter could not be maintained in the latter stages of growth as nitrogen acted as a limiting factor in such soils.

Percentage distribution of dry matter. The curves for leaves on the four types of soil will show that the percentage dry matter went on decreasing with the advance of age (Fig. 4, A, B, C, and D). The main differences between sandy loams (normal and saline) and light sandy soils (normal and saline) were (1) comparatively greater percentage of dry matter in the leaves of plants from light sandy soils than the percentage of dry matter in leaves of plants from sandy loams; and (2) the percentage distribution of dry matter in the stems was higher than that of the leaves on sandy loams, while the reverse was the case with the light sandy soils. On the light sandy soils the plant produced proportionately more leaf growth than the stem growth; while on sandy loams the plants produced more of stem than of leaf growth (Fig. 4, A, B, C, and D). The percentage distribution of dry matter in the bolls was higher on normal soils as compared with all the three types of soils where *tirak* appeared. Thus the *tirak* affected plants produced proportionately less boll material than the plants on normal lands. This was due to the suppression in growth of the bolls at the critical stage of fruiting period either due to the deficiency of water or nitrogen or both of them, depending on the type of the soil. Thus there are important differences between the percentage distribution of dry matter in the different parts of normal and *tirak* affected plants.

THE GROWTH AND DEVELOPMENT OF BOLLS OF NORMAL AND *tirak* AFFECTED PLANTS

The main symptom of *tirak* appear in the bolls which prematurely crack and contain immature or partially immature seeds with poor quality of lint which does not fluff out of the boll. The ginning percentage of bolls in *tirak* plants is higher than the ginning percentage in the bolls of normal plants. This is due to the fact that the seed weights are comparatively reduced in the *tirak* bolls. As the bolls from the *tirak* affected plant exhibited these symptoms it was necessary to determine the growth trends of the developing bolls from the time of their setting up to maturity in the *tirak* affected and normal plants. In order to study the growth of bolls from stage to stage it was first necessary to know the age of bolls. These determinations should also be made at regular intervals. The freshly opened flowers had therefore to be tagged on a certain date during the flowering phase so that the age of the boll could be easily known while sampling. Three fields, with normal sandy loams, saline sandy loams and light sandy soils deficient in nitrogen were selected for the

purpose on the Lyallpur Agriculural Farm. Light sandy soils with sodium clay were not included. For the sake of minimizing sampling errors, for each soil type four representative plots were selected at random in each field for sampling. On all sampling dates the samples were taken from all the plots to make it as uniform as possible. The flowers were tagged on the 26 September in the cotton season of 1940-41. About 5,000 flowers were tagged for each soil type (i.e. in all 15,000) as the setting percentage of flowers into bolls was about 30. During the first few stages a larger number of bolls from 100 to 200 had to be taken for the determination of dry weights as the newly-formed bolls were very small in size. In the later stages 50 bolls were taken on each sampling date. Samples for the dry weights were taken at weekly intervals. The bolls were immediately

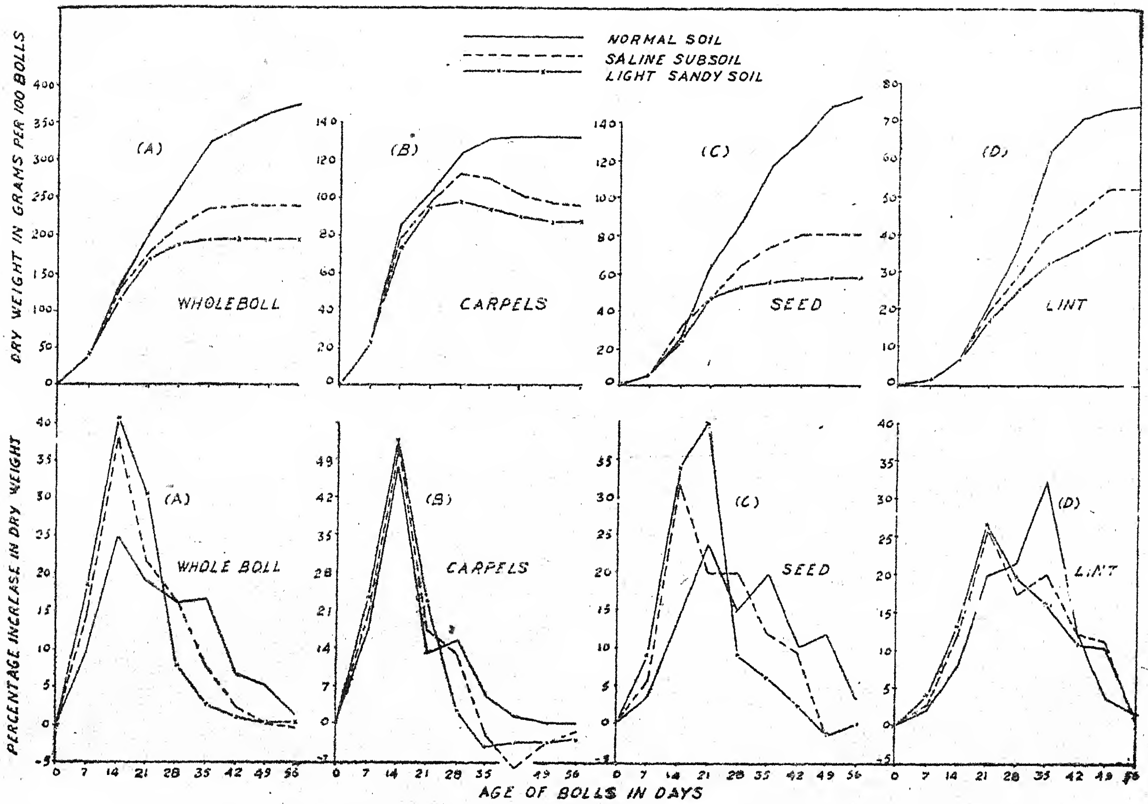


FIG. 5 (Upper part). Total dry weight in gm. per hundred bolls and their parts
FIG. 6 (Lower part). Percentage increase in dry weight of the boll and its parts

weighed after sampling. After recording the fresh weights they were divided up into stalks, sepals, carpels, seeds and lint. They were separately weighed and placed for drying in ovens, first at 50°C. and then at 70°C. and finally at 100°C. up till the weight was constant. Their dry weights were then determined. The moisture contents of the different parts of the bolls could then be calculated.

As the sampling was proceeded with, the number of opened bolls in the three types of soils was recorded. It was found that fully opened bolls began to appear on soils where *tirak* appeared on the 35th day after flowering. On the 42nd day about 40 per cent of the bolls had opened. In the case of normal sandy loam 44 per cent of the bolls opened between the 42nd and the 49th day and the remianing bolls opened after 56 days. Thus there was premature opening of the bolls on *tirak* affected plants.

The dry weights of 100 bolls beginning from the 1st week up to 8th week at weekly intervals were determined for the three soil types and the results are plotted in Fig. 5A. It will be seen that the bolls on the normal soils weighed much more than the bolls on the two types of soils where *tirak* occurred.

It was essential to know whether the differences in the dry weight of bolls under different soil conditions were statistically significant or not.

For this purpose, the data for the two consecutive years (i.e. 1940 and 1941) was utilized; and 'analysis of variance' was applied to the natural logarithms of the values. The point in taking the natural logarithms rather than the actual values needs no explanation. The results on the basis of statistical analysis are presented in Table I.

TABLE I

Natural logarithms of the dry weight of 100 4F developing bolls under different soil conditions

Age of bolls in days	Normal soil	Saline soil	Light sandy soil	Differences in pairs		
				Normal saline	Normal sandy	Saline sandy
1	2	3	4	5	6	7
7	3·661	3·522	3·509	0·139**	0·152**	0·013
14	4·881	4·860	4·682	0·021	0·199**	0·178**
21	5·342	5·182	5·092	0·160**	0·250**	0·090**
28	5·591	5·360	5·172	0·231**	0·419**	0·188**
35	5·804	5·430	5·195	0·374**	0·609**	0·235**
42	5·887	5·433	5·214	0·454**	0·673**	0·219**
49	5·933	5·427	5·200	0·506**	0·733**	0·227**
56	5·943	5·423	5·207	0·520**	0·736**	0·216**

** Significant at 1 per cent level. S.E. = ±0·0243

It is evident that the differences in the boll weights in the three soil types were significant among themselves. Furthermore, the differences started from the very beginning and they magnified as the development proceeded.

The dry weight of a boll on the saline subsoil was nearly two-third that of the dry weight of a boll on the normal soil. The dry weight of a boll was still less on the light sandy soil deficient in nitrogen. Another important difference between *tirak* affected and normal bolls was the absence of almost any increase in dry matter of the bolls of *tirak* affected plants after the 4th week (i.e. the 28th day stage). The dry weight remained almost constant after that stage on the two types of soils where *tirak* developed. Thus the cessation in the growth of bolls occurred after the 4th week from the day of setting of flowers on *tirak* affected plants while the growth of bolls on normal lands continued up to the 7th week stage. *Tirak* conditions was thus preceded by an inhibition of the growth processes, and the premature opening of the bolls consequently occurs.

The curve for the dry weight of the carpels and the seeds indicated the same characteristics (Fig. 5, B and C), that were shown by the dry weight curves of the whole bolls. There was a slight decrease in dry weight of the carpels after the 28th day stage in case of *tirak* affected plants. Thus when the cessation in growth of bolls occurred there was also a cessation in the growth of the carpels as well as the seeds. The case of the lint was however slightly different as it continued to grow and went on adding to its weight, even after the growth of the bolls had stopped. Though the dry weight of the lint of normal bolls was at all stages higher than the dry weight of lint of *tirak* affcted bolls, the increasing trends in the lint weight were clearly visible in all the three curves (Fig. 5 D.) The increase in the dry weight of the lint in the *tirak* affected bolls after the 28th day stage was just enough to make up for a slight decrease in the dry weight of the carpels, and thus there was no increase in dry weight of the entire bolls after that stage, indicating thereby that the lint was increasing in weight most probably at the expense of the carpels.

The curves for the percentage increase of the dry matter of the bolls at different stages of growth on the three soil types are given in Fig. 6A. The percentage increase in dry matter reached its maximum point on the 14th day's stage in the bolls from all the three types of soils under study. The noticeable feature was that the maximum point for *tirak* affected bolls was at a much higher level than the maximum point of the percentage increase in dry weight of the bolls on normal soils. About 40 per cent of the total dry matter was accumulated in the second week in the *tirak* affected bolls, while only 25 per cent of the total dry matter was produced in the good bolls during that week. This was so because the bolls on the normal soils went on adding to their dry weights up to the 49th day stage while the *tirak* affected bolls ceased to grow after 28 days. Consequently the percentage increase in the dry weight on the 14th day stage was higher in *tirak* affected bolls than on normal bolls. There was a steep and rapid fall in the percentage increase in dry weight after the 14th day stage in the *tirak* affected bolls, while the percentage increase remained at a higher level up to the last stage in the case of normal bolls.

The percentage increase in dry weight of carpels is given in Fig. 6B for the three soil types. The curves were typically growth curves obtained for the whole plant. The maximum percentage increase in carpels on the 14th day stage coincided with the maximum of the whole boll curve. The curves for the seeds on the other hand showed some differences. On the saline sandy loam the maximum percentage increase in dry weight occurred on the 14th day stage while on the normal sandy loams and light sandy soils the maximum was reached a week later. The seed curves (Fig. 6C) for normal sandy loams and for light sandy soils were almost identical in shape as the whole boll curves (Fig. 6A) with the difference in the maximum points, while the carpels and whole

boll curves of percentage increases in the dry weights were more or less similar. There was a secondary peak in the curve of the percentage increase in seeds and also in the whole boll in the case of normal soil as compared with soils where *tirak* occurred. This peak was reached on the 35th day stage and was due to the formation of oil and proteins during the fifth week in the seeds and also due to an increase in the weight of the lint. This view has also been confirmed by the results of the chemical analysis to be described in another contribution.

The maximum increase in the percentage dry weight of the lint occurred on the 35th day stage on normal sandy loams while in the two soil types where *tirak* occurred, the maximum increase occurred a fortnight earlier, i.e. on the 21st day stage (Fig. 6D).

Thus the periods from the 7th day to the 21st day for *tirak* affected bolls and from the 7th day to the 42nd day for normal soils appeared to be important and any unfavourable climatic factor during that period was likely to affect the growth of the bolls adversely. It may be mentioned that when *tirak* occurred in an extreme form in certain years on account of hot and dry weather in the months of September and October, the bolls of this age were found to be most affected. They ceased to grow and opened badly. The phenomenon was most marked on soils with medium salinity where under favourable weather conditions no cessation in growth normally occurred. Once the growth ceased in such years at that important period, the bolls remained in that very condition except that they began to loose moisture and to crack with immature seeds and weak fibre.

The growth of the bolls on the three soil types was again studied in the cotton season of 1941-42 and the growth curves obtained in the second year were identical with those of the previous year and showed the same characteristics discussed above.

The percentage distribution of dry matter in the different parts of the bolls in the three types of soils are given in Fig. 7 (A, B, and C). On normal soils the percentage distribution curve for carpels intersects with percentage distribution curve for seeds. There was more dry matter in the seeds than in the carpels at the final stage. The case was different with bolls of *tirak* affected plants. The maximum quantity of dry matter at all stages was in the carpels of *tirak* affected bolls, and the seed weight was lower than normal (Fig. 7, B and C). The differences between the percentage dry matter of the carpels and the seeds were greater on light sandy soil than on saline sandy loam. The lesser dry matter in the seeds was due to lesser amount of oil and proteins in the *tirak* affected bolls, than in normal bolls. The percentage distribution of dry matter in the lint was almost the same on the three types of soil. The lint alone contributed about 20 per cent of dry matter of the whole boll.

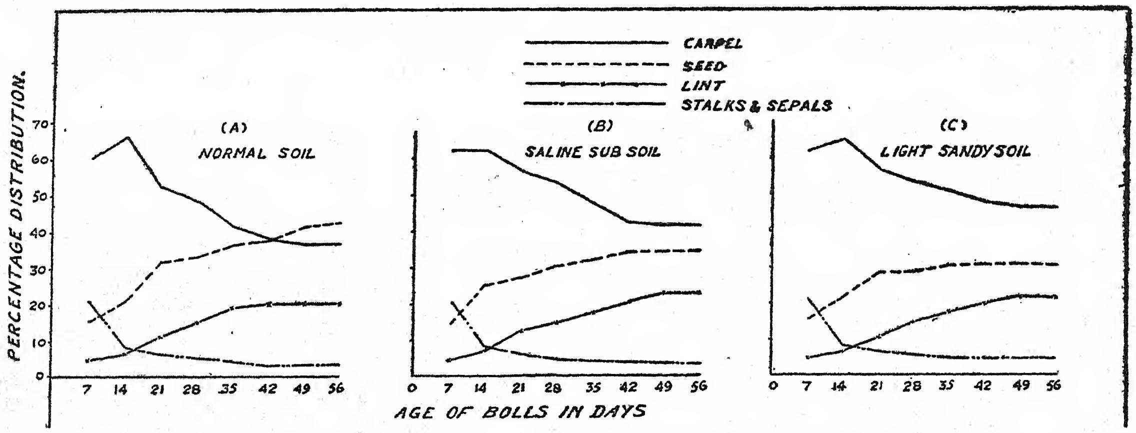


Fig. 7. Percentage distribution of dry matter in the different parts of the 4F bolls

Volume, weight and density of bolls

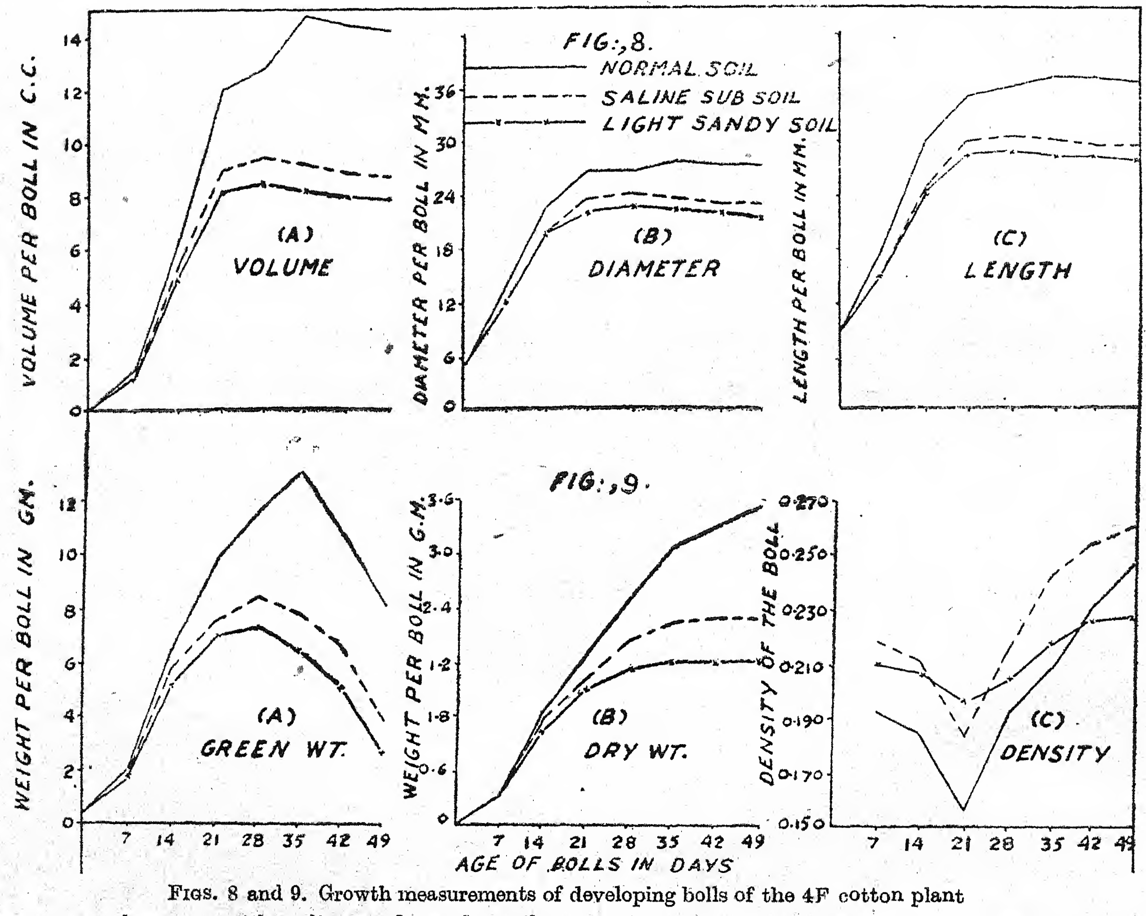
In order to study the growth trends and to find out the most important period in the development of bolls it was also necessary to find out the volume, the weight, the length, the diameter and the density, etc. of bolls at various stages of growth. Martin, Ballard and Simpson [1923] measured the growth of fruiting parts in the various varieties of the cotton plants. They conducted their experiments in the different parts of America on different varieties of Egyptian and Upland cottons. They found that the most important period for volume, weight (dry and fresh), length and diameter of cotton boll was the first three weeks after setting.

Samples of bolls were taken from normal sandy loams, saline sandy loams and light sandy soils at weekly intervals in 1940-41 season. For volume,

length and diameter, values of six average bolls at each stage of growth were taken and arithmetical mean was calculated for the final average values. For green weight and dry weight the average of 50 bolls was taken. Volume was measured in cubic centimeters and the length and diameter in millimeters with the help of Vernier Caliper. Percentage increases and density, etc., were calculated from these values. In all these measurements stalks and sepals were removed.

Volume. The volume of the boll began to increase rapidly after setting. About 90 per cent of the final volume of the boll was formed in the first three weeks as this was the most active period of boll development. In the case of 'normal soils', the maximum volume was 14·66 c.c. per boll and it was attained five weeks after setting. After this stage as the boll matured, it began to shrink slowly both in length and diameter and a decrease in the volume was thus caused. In the case of saline and light sandy soils the maximum volume was 9·5 c.c. and 8·5 c.c. per boll respectively, which were reached after four weeks instead of five and the boll began to shrink gradually thereafter (Fig. 8A).

In the case of normal soils percentage increase in volume was very high in the second and third weeks and peak was reached after 21 days. The



FIGS. 8 and 9. Growth measurements of developing bolls of the 4F cotton plant

same was the case with saline and sandy soils except that the maximum percentage increase occurred on the 14th day stage.

Length or the 'major axis' of the bolls. The maximum increase in length of the boll in all types of soils occurred in the first three weeks after setting. In the normal soil the maximum length was 37·27 mm. which was reached after 35 days; while in the saline and sandy soils the maximum lengths per boll were 30·28 mm. and 29·07 mm. respectively; which were reached a week ealier. After attaining the maximum length it began to shrink gradually due to loss of moisture (Fig. 8C).

The percentage increase in length showed that the first three weeks were very important and 90 to 95 per cent of the length was formed during this period. The peak in all soil types was reached after 14 days, thus the maximum increase in volume and length occurred almost at the same

time. On normal soils the bolls were therefore definitely bigger than the bolls on soils where *tirak* occurred.

Diameter or 'minor axis' of the boll. The growth in diameter was similar to that of the length of the boll on all soil types (Fig. 8B). The peak was reached in all cases after 14 days.

Ratio of length and diameter (*Length/diameter*). In the normal soils this ratio varied from 1·29 to 1·36, in saline soils from 1·27 to 1·32 and in the light sandy soils from 1·26 to 1·33. The ratio remained fairly constant indicating that the growth proceeded symetrically on all sides of the bolls.

Fresh weight and dry weitght per boll. There was a rapid increase in green weight of the bolls which reached its maximum after 35 days on the normal soils and after 28 days on the saline and light sandy soils. After reaching the maximum the fresh weight began to decrease. It decreased more rapidly in the bolls of *tirak* soils than in the bolls of normal soil. This was due to premature drying and cracking of bolls in the former case. The dry weight went on increasing till the end in the normal soil while in *tirak* soil it became more or less constant after the 4th week (Fig. 9, A and B).

Density of the bolls. The density graph of the bolls revealed very important features (Fig. 9C). Though there was an increase in green and dry weights from the 7th day stage up to the 28th day stage on all the three soil types, there was a marked fall in the density of the bolls from the 7th to the 21st day stage. This fall in the density was due to the largest percentage increases in volume up to the 21st day stage. The increase in volume may not wholly be due to the additions of dry matter but it may also be due to extension growth of the cells of the carpels. The carpels grew more rapidly than the seeds at this stage and this lead to the formation of cavities in the bolls where air entered. Thus reduction in weight per unit volume can occur. On normal soils the density of the bolls was the lowest on the 21st day stage, while it was higher on saline and sandy lands. The growth of the carpels was, therefore, not so rapid in *tirak* affected bolls as in normal bolls. The density of boll rose from the 21st day stage on all the three types of soils. The density of bolls on saline soils was higher than the density of the bolls on normal soils though the dry weights of the bolls in the two types of the soils were in the reverse order. The greater mass per unit volume of the bolls on saline lands where the dry weight per boll was less than the dry weight per boll on normal soils may be due to lesser volume of air in the boll in the former case. In case of light sandy soils the final density of the bolls was slightly lower than the normal bolls. The density was found by the weight/volume standard method.

The degree of maturity of seeds based on the colour of outer tests. As the cotton seed developed it changed its colour from white to greyish green and finally attained dark blue black colour. In the year 1941-42 on all sampling dates a representative sample of seed from the boll, of all the three soil types under study, was taken and divided into three groups, viz. white (fully immature), greyish green (partially immature), and blue black (fully mature); and the percentage of each type was calculated at different stages of growth.

In the normal soils up to the 14th day stage all seeds were white, and after 21 days only 5·30 per cent turned greyish green. After 35 days it was found that nearly 78 per cent of seeds were greyish green. These grey-green seeds then went on turning into dark bluish black in colour. This change occurred mostly when the seeds were of 42nd to 49th day stage. Finally, after 56 days it was found that 91 per cent of the seeds were blue black in colour (fully mature), 7 per cent greyish green (partially immature) and about 2 per cent white (fully immature) in bolls from the normal soil under study. In case of saline soil the colour of seeds turned grey-green and finally black at an early date, but this change from grey-green to black slowed down after 42 days. Finally, after 56 days it was found that fully mature seeds were 45 per cent, partially immature 25 per cent and fully immature white seeds 30 per cent of the total. On the light sandy soils the only difference was that the white seeds began to turn greyish green after 21 days' age. At the end 36 per cent were fully mature, 30 per cent partially immature and 34 per cent were fully immature and white seeds.

Total number of seeds per boll was also counted in a number of bolls. In the case of normal soils it varied from 30 to 35, with an average of 31·66 per boll; while in saline sandy loams and light sandy soils the number varied from 17 to 25 per boll with an average of 22·50 and 21·60 respectively.

Moisture. The moisture contents of the different parts of the bolls on the three soil types indicated a higher moisture content in all parts of the normal boll (expressed on 100 gm. of dry matter).

Summary

There were not marked differences in the growth rate curves of normal and *tirak* plants. There was a depression in the relative growth rate of plants on sandy loams with saline subsoil in the months of September and October. On light sandy soil the reltative growth rate was higher than that of the plants on normal sandy loams during

the early stages of the growth. This was due to the very sandy nature of the soil in the former case.

Similar differences were found in the net assimilation rate of plants on these types of soil.

The percentage distribution of dry matter in bolls was higher on normal sandy loams than on soils where *tirak* occurred. On light sandy soils with sodium clay in the subsoil the percentage of the dry matter in the bolls was the least.

The study of the growth of bolls at weekly intervals on normal and on soils where *tirak* condition appeared showed that the growth of the bolls of *tirak* affected plants ceased after the 28 days' stage. There was no increase in the dry matter of the whole boll after that stage. The same remarks applied to the carpels and seeds individually. But the case of lint was different. Lint continued to increase in weight even in *tirak* affected plants up to the 49th day stage. In the case of normal bolls growth continued up to the 49th day stage in all its parts. The dry matter per boll in *tirak* affected plants was nearly one half of the dry matter per boll on normal plants. Thus the bad opening of the bolls was preceded by a cessation of growth which generally occurred in the 5th week after setting.

The volume, length and diameter of bolls from *tirak* affected plants were less than those of the bolls of normal plants indicating bigger boll size in the latter. The maximum increase in dimensions occurred during the first three weeks after setting. The bolls from the normal plant contained about 91 per cent of the fully mature seeds while the bolls from *tirak* affected plants contained 30 to 36 per cent of fully immature seeds and 25 to 30 per cent of partial immature seeds and the rest were mature seeds.

Moisture was more in all parts of good bolls as compared with the *tirak* affected bolls.

Total number of seeds per boll in the normal soil varied from 30 to 35 with an average of 31·66, while in the saline and light sandy soils it varied from 17 to 25 per boll with an average of 22·50 and 21·60 respectively.

It was thus clear that the growth of the bolls did not exihibit normal trends when *tirak* occurred and the cessation in growth of the bolls preceded the *tirak* condition. When the seasonal conditions are adverse during the fruiting stage the development of the bolls is affected on a larger area than normal, i.e. on soils with medium or low salinity also the effect is pronounced, and thus cotton failures are caused.

ACKNOWLEDGEMENT

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BIG BUD DISEASE OF THE TOMATO

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(With Plates II and III)

BIG Bud, an abnormal condition of the tomato, was described for the first time by Cobb [1902] in New South Wales. The virus is present in all the Australian states and apparently a similar disease has been reported from Russsia by Michailowa [1935] though under a different name. In the Pacific North West the occurrence of Big Bud has been reported by Dana [1940].

Studies on virus diseases of tomatoes have been in progress at the Imperial Agricultural Research Institute, New Delhi, for the last

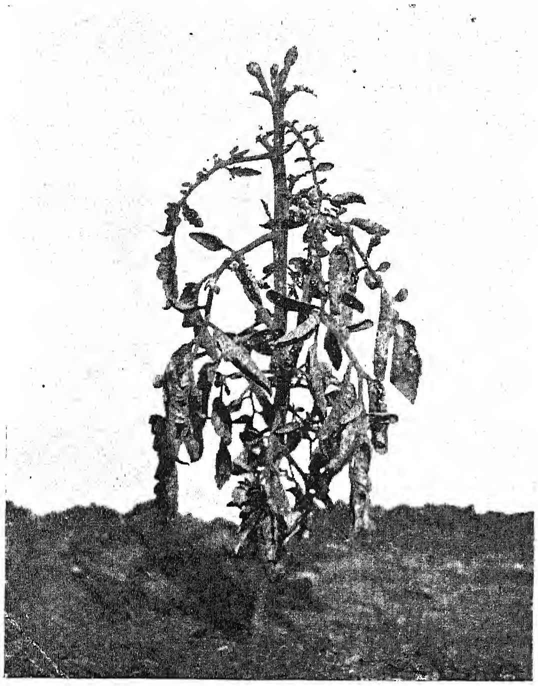

FIG. 1. An infected tomato plant var. Sutton's Early Market showing symptoms of disease

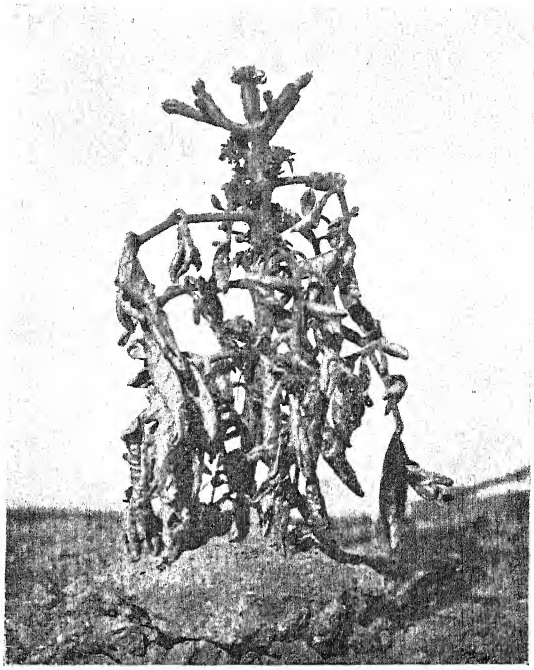

FIG. 2. Later stage of disease

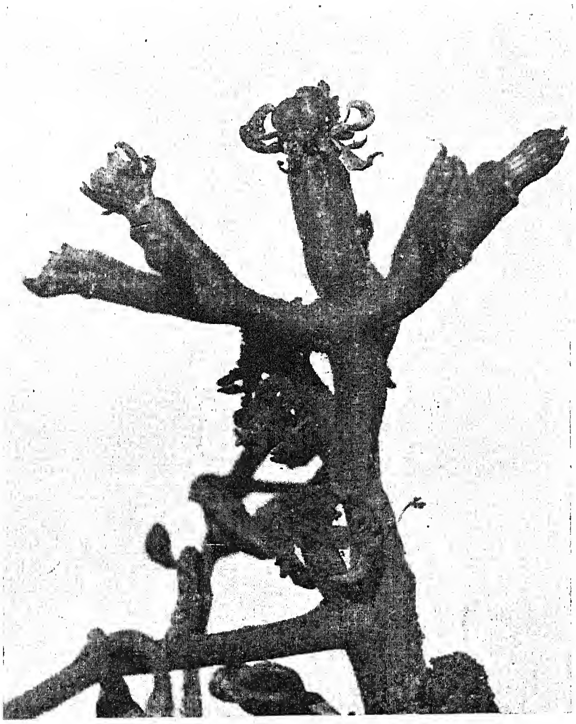

FIG. 3. A close view of the affected flower truss showing thickened pedicel

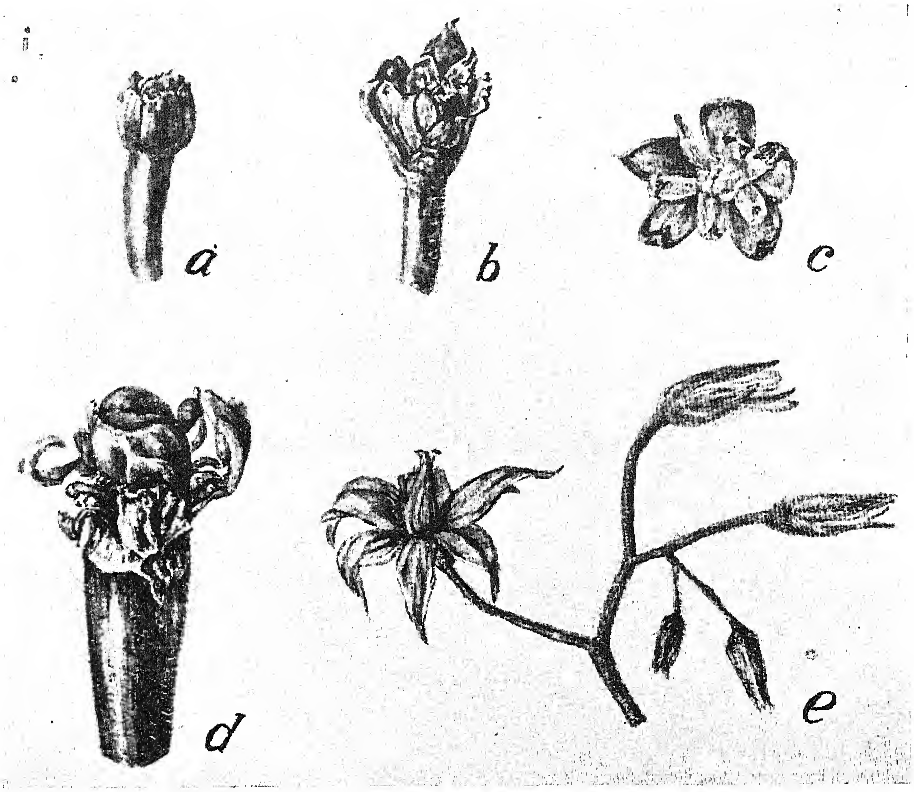

FIG. 1–*a*. Thickened calyx adhered to each other and forming a tube
b. and *c*. Side and top view of an affected flower which has been opened to show the internal organs. Note the virescent petals which are drying at the tips
d. Thickened pedicel, dried calyx, thickened and virescent corolla and lobed fruit
e. A normal flower truss from a healthy Tomato plant var. Sutton's Early Market

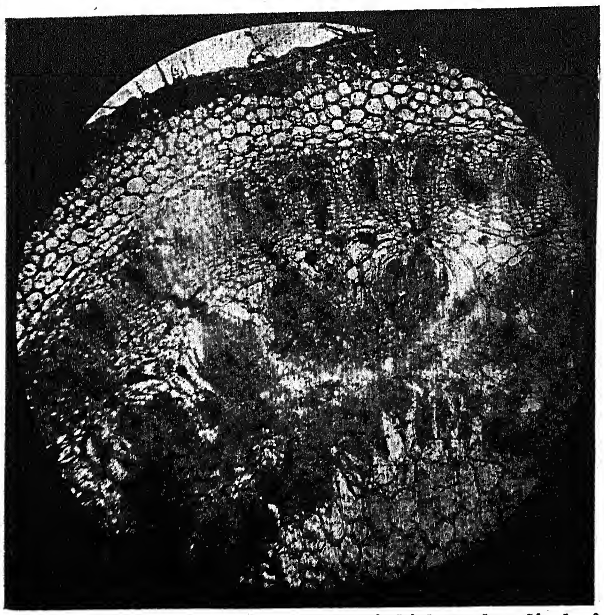

FIG. 2. Photomicrograph of T.S. of thickened pedicel of an effected flower showing abnormal tissue in close association with phloem

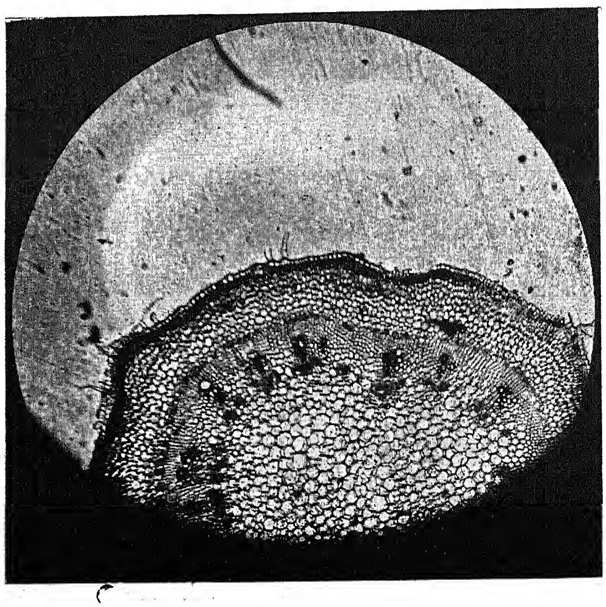

FIG. 3. Photomicrograph of T.S. of normal pedicel

three years and in this connection the tomato crop has been occasionally examine in the Punjab, United Provinces and Bihar. In the winter of 1943, only two tomato plants of variety Sutton's Early Market in the mycological area of this Institute exhibited an abnormal condition resembling that of Big Bud, i.e. *Lycopersicum virus* 5 [Smith, 1937]. This disease has so far not been reported from this country and is described in this paper.

SYMPTOMS OF THE DISEASE

The first symptom of infection appears almost simultaneously at the tips of actively growing shoots and on the leaves. The leaves get thickened, show upward rolling of margins and point downwards. At a later stage the leaves become intensely thickened and brittle and may at times show typical rolling. The youngest leaves which appear after the infection has taken place show light mottle and the lateral leaflets are reduced in size. There is also purpling of leaves particularly on the under surface due to the production of anthocyanin in the cells. The plant assumes an erect habit and the growth is arrested soon after infection has taken place (Plate II, figs. 1 and 2). Another effect of the virus is to stimulate the production of lateral growths on the stem from the axils of the leaves. The growth consists of a cluster of minute leaflets forming dense rosette like structures. These leaflets also are deep purple in colour.

The effect of the disease is simultaneously exhibited on the youngest fruit truss which becomes erect instead of being recurved as in normal plants. The fruit buds in the truss also assume an upright position. As the growth of terminal buds ceases, there is a gradual thickening of the stem and pedicel. The thickening increases with age and sometimes two pedicels may fuse together and appear as one (Plate II, fig. 3). The six segments of the calyx increase in size and thickness and form a sort of inflated tube so as to enclose the floral organs. The calyx segments are not linear or lanceolate as in normal plants but become oblong; they may be united or may remain adhered to each other without actually being united (Plate III, fig. 1-a). In due course the calyx segments become purple in colour and later dry up.

The corolla also undergoes a marked change. It becomes either enlarged or stunted, is thickened and becomes completely virescent. The six petals, though remaining separate, form a sort of an enclosure for the internal organs, e.g. carpel and gynœcium. The tips of the petals may dry up. At times one or two pairs of petals may get united at or near the base. The conversion of petals into leafy structures is a characteristic effect of the malady. (Plate III figs. 1-b and c).

The anthers are also appreciably reduced in size. They are light green or whitish in colour, unlike those in normal flowers in which they are always yellow and much larger in size. There is no marked difference in the size of filaments. The anthers are situated singly between phylloid petals and are not united as in normal flowers in which they form a tube around the style.

The style is short and is of the same colour as that of the anthers. Phylloidy of the carpel and the carrying of the gynoecium on the proliferation of the central axis of the flower, as described by Samuel, Bald *et. al.* [1933] has not been observed, probably because of the small number of affected plants available for examination. The ovary appears to be slightly larger than that of the normal flowers. There is an additional growth of the central placental tissue in each locule and the number of ovules is consequently comparatively reduced.

The diseased plants may or may not set fruits. The fruits when formed are very small, being comparable in size and shape to linseed fruit. The fruit is thick skinned, hard and pointed. It is usually of dull green colour and is often lobed and sometimes distorted. Such fruits neither mature nor form seed (Plate III, fig. 1-d).

Anatomical changes associated with the much thickened pedicel were studied by cutting transverse sections. Development of an abnormal tissue close to the phloem is observed. This tissue is even visible with the naked eye as a circular band when the pedical is cut transversely. Plate III, figs. 2 and 3 show photomicrographs of transverse sections of affected and healthy pedicels respectively.

TRANSMISSION OF THE DISEASE

Tomato plants of the variety Sutton's Early Market of varying ages were inoculated with fresh juice of the diseased plants which was extracted in a sterilized pestle and mortar and strained through fine muslin. Inoculations were carried out by dusting the leaves with finely powdered carborundum and smearing the leaves with the juice with a piece of absorbent cotton wool. In another set of inoculations the leaves were smeared with diseased plant juice and the surface of the leaves was pricked with sterilized needle but all efforts to

transmit the disease by mechanical means were unsuccessful.

Buds removed from diseased plants were grafted to healthy tomato plants but the number of grafts was rather small because of the scarcity of the diseased material. The disease was transmitted to healthy plants wherever budding was successful.

The results of transmission tests are summarized in Table I.

TABLE I

Transmission of the disease

Expt.	Date of inocula-tion	Method of inoculation	Age of plants (days)	Number of plants inocula-ted	Number of plants Infected	Time required for Infection (days)	Remarks
I	8-12-43	Juice inoculation with carborundum and needle scratch	60	6	0	..	..
II	8-12-43	Juice inoculation with carborundum	23	12	0	..	..
III	27-11-43	Budding	90	5	2	48	3 buds dried up and grafts were not successful
IV	1-12-43	Budding	45	2	..	..	..
V	21-1-44	In arhcing . . .	40	1	1	105	Dried up

SUMMARY

1. Occurrence of 'Big Bud' (*Lycopersicum virus* 5) disease of tomato has been reported.

2. Erect habit of the plant and abnormalities in the floral organs such as adhesion, virescence and certain types of overgrowth are characteristic symptoms.

3. The pedicels of the affected flowers are much thickened due to the formation of an abnormal tissue in the phloem region.

4. The disease has been successfully transmitted by grafting but efforts to transmit the disease by mechanical means were unsuccessful

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ON THE OCCURRENCE OF *COLLETOTRICHUM CAPSICI* IN CHINA

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(With two text-figures)

COLLETOTRICHUM *Capsici* (Syd.) Butler et Bisby was originally described from Madras Presidency (India) in 1913 [Sydow]. Its occurrence in China was reported by Sydow [1919] from Canton and by Teng [1938] from Kwangsi. Recently, this fungus has been noticed to cause a ripe rot of fruits of pepper, eggplant, and tomato in Chengtu Plain, Szechuan Province. During wet seasons, it may result in considerable damage, especially in pepper and tomato. In order to ascertain the identity between isolates from different hosts and with the Indian fungus, morphological and cultural studies and inoculation experiments have been undertaken since 1941.

GEOGRAPHIC DISTRIBUTION

The fungus has been reported from Madras, Bihar, Bombay, and Bengal in India, and from Canton, Kwangsi, and Chengtu in China.

Besides, its appearance from widely separated regions in Asia, Africa, and North and South America has been recorded from time to time. Its natural host is chiefly the cultivated chilli pepper, but its attack on eggplant and tomato has been reported by Thompson [1928] from Malaya. In Kenya, McDonald [1924] has noticed on Madagascar butter bean, *Dolichos lupiniflorus*, and pigeon pea a similar fungus, which, however, appears more probably to be related to *Colletotrichum truncatum* (Schw.) Andrus et Moore rather than to *C. Capsici.* The report of Deighton [1936] of the fungus as a cause of fruit rot of papaw in Sierra Leone also needs further verification. On the other hand the fungus that causes pepper rot in the Philippines and has been regarded as *Colletotrichum nigram* Ell. et Halst. by Malabanan [1926], as pointed out by Higgins [1930] is probably *C. Capsici.* As most reports have come from southern Asia, the fungus is most likely to be originated from that region and has spread to Africa and America in relatively recent times.

Based upon the literatures abstracted in the Review of Applied Mycology, the distribution of this fungus is mapped out in Fig. 1. An examination of the map reveals that notwithstanding its wide occurrence in separate continents, its habitat is apparently limited to the tropical and subtropical regions only. With the exception of its occurrence in Argentine, the fungus has been recorded exclusively within the zone northward from the equator to latitude 32°. Middle Georgia of the United States appears to be the northern boundary. Buenos Aires, Argentine, is the only spot where the fungus has been reported lying in the southern side of the equator at approximately 35°. The record from the last-named locality has been based upon an isolate from the fruit of chilli affected by a die-back. In view of the common occurrence of saprophytic species of *Colletotrichum* on dead

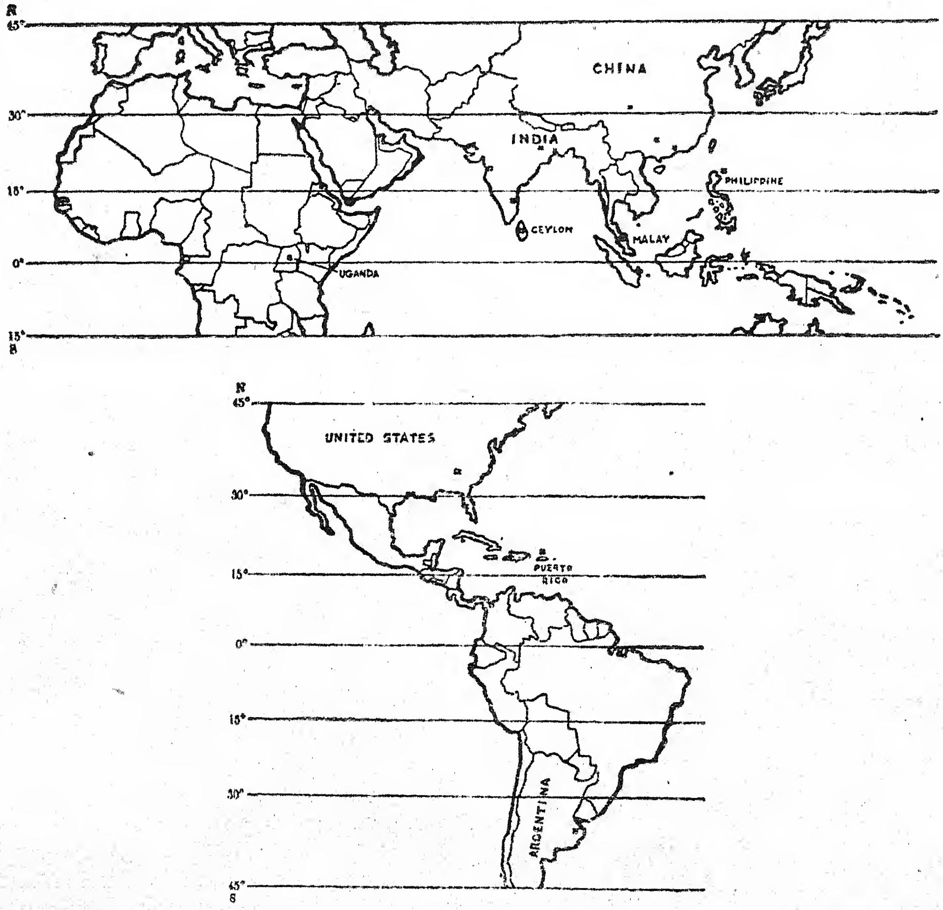

FIG. 1. Distribution of *Colletotrichum Capsici* ⌗ (indicates where the fungus has been reported).

or apparently healthy parts of plants, the correctness of its identity seems dubious.

MORPHOLOGY

The morphology of *C. Capsici* has been described several times [Dastur, 1921; Higgins, 1930; Sydow, 1913; and Teng, 1938]. It has falcate conidia, thick stroma, conspicuous and abundant setae, and densely aggregated acervuli (Fig. 2, A and B). In comparison with a number of species of *Colletotrichum*, such as *C. circinans* (Berk.) Vogl., *C. indicum* Dast., *C. truncatum*, and *Glomerella Glycines* (Hemmi) Lehman et Wolf, it differs from them in no essential way.

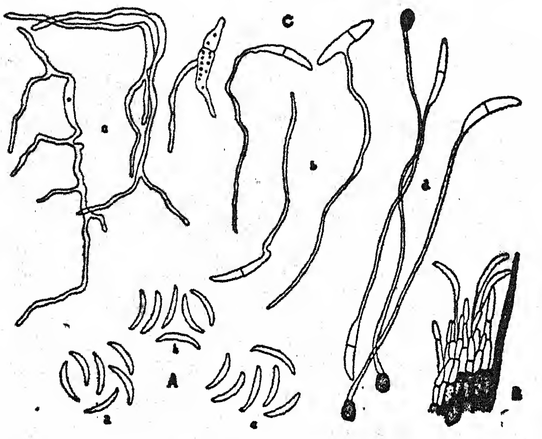

FIG. 2. *Colletotrichum Capsici*—
A—Conidia ; a—Tomato isolate ;
B—Acervulus ; b—Eggplant isolate ;
C—Germination of conidia × 250 ; c—Pepper isolate

Sydow [1913] first gave the measurements of its acervuli 70-120 μ setae 70-145 μ, and conidia 17-28 × 3-4 μ. Measurements obtained from the cotype material, as presented in Sydow's Fungi exotici exsiccati no. 199, are very close to the original. The American fungus seems to have somewhat smaller measurements, being reported by Higgins [1930] as 48-96 × 3·5-6 μ and 16·8-26·4 × 3-4·2 μ for setae and conidia respectively. On the other hand, the Philippine fungus has larger conidia, being reported as 23-31·1 × 3·66-3·93 μ. The material obtained in Chengtu has been studied in detail. The measurements, taken from both host plants and agar cultures, of different isolates from pepper, eggplant, and tomato (Table I), indicate a very close similarity between isolates and also justify its identity with the Indian fungus. Substratum exerts a definite influence on the size of conidia. Those produced on agar medium are longer in average than those produced on hosts.

In germination, the three isolates from different hosts behave somewhat differently. In the pepper isolate, the germ tubes have broader diameter and branch profusely soon after germination. In the other two isolates, the germ tubes usually grow for several hundred microns long without branching. The appressoria formed at the tips of germ tubes when contacted with glass are present only in the tomato isolate, but absent in the other two (Fig. 2, C).

CULTURAL CHARACTERISTICS

While growing in cultural media, the isolates of the fungus from pepper, tomato, and eggplant are very similar to each other. Among the media tested, the ordinary potato-dextrose agar appears to be the most favourable one. On that medium the aerial growth is fluffy, Mouse Gray in colour [Ridgway, 1912], thick in centre, becoming thinner toward the edge. The margin of the colony is whitish, appressed and entire. The submerged growth is composed of both hyaline and brown hyphae. The brown hyphae are thick-walled and swelling in places to simulate chains of chlamy-dospores. They are loosely aggregated to form a sort of cushion and appear to naked eyes as black dots, scattered or arranged in rings, from the bottom view of the cultural dishes. They are probably what Dastur [1921] describes as stromatic plates. The setose sclerotial bodies or acervuli are either scattered or arranged in concentric rings, up to 1 mm. in diameter, and vary in abundance in different strains. Sporulation is in general abundant. The conidia are produced either in acervuli as pinkish or creamy masses or on the aerial hyphae. The statement of Dastur [1921] that the aerial haphae do not produce conidia has not been confirmed, although the conidia produced in such a way are usually smaller than those formed in acervuli. On corn meal agar, the aerial growth is rather scanty and light grayish in colour. The margin of the colony is fimbriate. The submerged growth is whitish and spreading radiately toward the margin, being composed of the same sort of aggregated hyphal cushions as observed in potato-dextrose agar. Sporulation is generally poor, the acervuli being found scatterly only in the pepper isolate but none in the other two isolates.

Sterile plant tissues, such as cylinders of potato, sweet potato, and carrot, are in general favourable media for the growth and sporulation of the fungus. The aerial growth is abundant and of varying shades of Olive Gray. Mycelial tufts often arise as saltants, Light Drab to Light

TABLE I

Measurements of Colletotrichum Capsici *from different hosts*

Sub-stratum	Original host	Diameter of acervuli in μ	Size of setae in μ		Size of conidiophores in μ		Size of conidia in μ	
			Range	Mean	Range	Mean	Range	Mean
Host plant	Pepper .	86—240	57·8—134 × 5·7—7·5	101×7·0	14·3—22·8 × 2·5—4·0	17·4×3·5	18—28·6 × 2·8-4·2	24·9±·404 × 3·4±·159
	Tomato	97—288	62·5—165 × 5·7—7·2	123×6·5	15·0—26·8 × 2·8—4·2	20·2×3·8	17—29·0 × 2·8—4·2	25·0±·481 × 3·6±155
	Eggplant	74—187	86—150 × 4·2—8·5	118×6·9	17·1—25·4 × 2·8—4·2	18·6×3·4	17—28·6 × 2·8—4·2	25·1±·452 × 3·5±·156
Potato-dextrose agar	Pepper .		86—200 × 4·2—7·0	143×5·7	25—28·6 × 2·8—4·2	26·0×3·8	17—29 × 2·8—4·2	22·4±·427 × 3·7±·193
	Tomato		57—240 × 4·2—5·7	167×5·0	17—25·0 × 2·8—4·0	19·4×3·3	17—28·6 × 3·0—4·3	23·4±·029 × 3·8±·030
	Eggplant		87—286 × 4·2—7·1	176×5·0	19—30·4 × 3·0—5·0	24·4×4·1	17—27 × 2·8—4·2	22·3±·017 × 3·8±·030

Pinkish Cinnamon in colour. Potato cylinder seems to be a better medium for the sporulation than the others.

In aged cultures of this fungus, no matter what kind of medium is used, a sort of hair-like growth, a few mm. long, is constantly produced. It consists of a bundle of aggregated dark hyphae and often produces conidia on the tips. It protrudes densely along the margin of the colony in tube cultures and grows downward to the bottom in Petri dishes.

In essentials, the cultural characteristics of *C. Capsici* are quite similar to *G. Glycines* from soybean and *C. truncatum* from garden bean.

PATHOGENICITY

Experiments of artificial inoculation carried out by Dastur [1921] and Sundararaman [1927] revealed that *C. Capsici* is capable of infecting a number of plants, chiefly the fruits. Based upon the experimental host range, this fungus can only be differentiated from several other closely related fungi with difficulty.

In order to compare different strains of this fungus and with a few other local species of *Colletotrichum* having similar morphology, inoculation experiments have been made. The fruits of tomato, pepper, and eggplant, which are natural hosts of *C. Capsici*, are readily subjected to the attack of this fungus. In agreement with the finding of Higgins [1930], the young unripen fruits are equally susceptible to infection but the rot will not develop until the fruits ripen. Inoculation of the fungus on flower parts results in blossom blight, while die-back phase of the disease, though common in India [Dastur, 1921], has been observed neither in nature nor after artificial inoculations.

Inoculated on the detached fruits or tubers of several plants, the three isolates of *C. Capsici* and *G. Glycines* behave similarly in being able to infect tomato, pepper, eggplant, and soybean, but not potato and cotton (Table II). *C. indicum* from cotton is distinguishable from them in its ability to cause rotting on cotton bolls.

C. Capsici is readily differentiated from *G. Glycines* and *C. indicum* in its inability to attack its natural hosts during the seedling stage after soaking the seeds in the conidial suspension. While seedlings of soybean and cotton inoculated with *G. Glycines* and *C. indicum* respectively damp-off completely after emergence, both fungi fail to attack other plants than their own suspects. Those plants inoculated with the three isolates of *C. Capsici*, however, remain, healthy.

Sundararaman [1927] reported that *C. Capsici* and *Collectotrichum Curcumae* (Syd.) Butler et Bisby, originally described from *Curcuma longa*, have similar host range in India. Among those hosts recorded, a few have been included in the present experiments of inoculation. Vigorously growing plants of cabbage, *Solanum nigrum*, and *Datura alba* are immue to the attack of all the three isolates of *C. Capsici* at different stages. The lower leaves of cabbage, while beginning to turn yellow, and the detached fruit clusters of the other two plants, however, become infected readily. On such declined plant organs the fungus fructifies profusely.

TABLE II

Results of inoculation of* Colletotrichum Capsici, Colletotrichum indicum *and* Glomerella Glycines *into fruits or tubers of different plants

Plant inoculated	*C. Capsici* from indicated host			*C. indicum*	*G. Glycines*
	Pepper	Tomato	Eggplant		
Cotton boll	..a	..	..	++	..
Soybean pod	+a	+	++	++	++
Tomato fruit	+	++	+	+	+
Pepper fruit	++a	++	++	++	++
Eggplant fruit	++	+	++	+	+
Potato tuber	..	..	..	..	..

a—indicates no infection; + infection only through wound; and ++ infection through both wound and healthy tissue

DISCUSSION AND SUMMARY

Within the genus *Colletotrichum* there are a number of species with conidia falcate in shape. Their thick stromata had been mistaken as imperfect pycnidia or sporodochia in old literatures. Thereby, most of such species were treated as *Vermicularia*, which had recently been proved to be nothing but a synonym of *Colletotrichum*. Those species are mostly similar to each other in morphology. The measurements of conidia and other structures are fairly variable and in most cases overlapping between species, and hence cannot be always relied upon as a satisfactory criterion for their specific separation. The shape of conidia may serve in distinguishing species in a few cases. For instances, *C. atramentarium* (B. et Br.) Taub. is characterized by its cigar-shaped conidia and *C. fructus* (S. et H.) Sacc. has conidia with walls nearly parallel throughout the middle half and one end tapering much more abruptly than the other. In habitat, those species vary from sapyrophytic to strongly pathogenic. When inoculated on ripe succulent fruits, most of them are able to cause decay of varying degrees. Within that group of fungi, the ascigerous stage has not so far been discovered, except in one case, i.e. *G. Glycines*. Based upon the conidial stage alone, their taxonomy is a much confused matter. With future advancement in the knowledge regarding their genetic connection, they may be proved as distinct valid species. On the other hand, it is not impossible that they may be eventually proved as merely conidial strains belonging to one single ascigerous fungus, as in the case of *Glomerella cingulata* (Stonem.) Sch. et Spauld.

C. Capsici is a fungus belonging to the above-mentioned group. Its distribution has been recorded from Asia, Africa, and South and North America, but chiefly limited to tropical and subtropical regions. The three isolates from pepper, tomato, and eggplant found in Chengtu, Szechuan Province, are very much alike in morphology and cultural characteristics, and agree well with the original description and the cotype material of the fungus. It is a weak parasite, causing a ripe rot of fruits of its natural hosts under favourable conditions. In comparing it with *C. indicum* from cotton and *G. Glycines* from soybean, no remarkable difference in morphological characters can be observed. The only thing which serves to distinguish them is pathogenicity. The latter two species are both capable of killing their respective hosts at the seedling stage, while *C. Capsici* is unable to do so.

Based upon his cross-inoculation experiments, Sundararaman [1927] believes *C. Curcumae* to be identical with *C. Capsici*. Since the

former species has not been found in this region and the latter fungus that Sundararaman had worked with has apparently a much wider host range than that we have, a comparable experiment cannot be carried out to confirm this finding. However, it is still doubtful if any plant could be eventually found to serve as a differential host for these two fungi. Moreover, as shown by the results of our experiments, for the purpose of differenting those fungi by pathogenicity, actively growing plants should be used instead of ripe succulent fruits and weakened plant organs which in fact will give no reliable indication of infective capability.

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STUDIES IN THE PRESERVATION OF FRUITS AND VEGETABLES

EFFECT OF MATURITY OF WILLIAM'S PEARS (KULU VALLEY, PUNJAB) ON THEIR CANNING QUALITY

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(With one text-figure)

Prior to conducting semi-commercial trials on the canning of William's Pear [Lal Singh and Girdhari Lal, 1941] from Kulu Valley, it was observed in preliminary work on standardizing the method of canning, that general physical appearance and condition of the fruit depending upon its maturity had a marked effect on its canning quality.

Detailed studies regarding the changes in colour, firmness and other physical and chemical properties of Bartlett Pears (known as William's Pear also) in relation to appropriate time of picking for transportation purposes, etc. in various parts of United States of America have drawn the attention of Alien [1929] and Magness *et al.* [1929]. Work of similar nature on fruits like apples [Magness *et al.*, 1926] and peaches [Culpepper and Cladwell, 1930] has been reported. It has been shown by these authors that attempts to measure chemical changes (i.e. percentage of solids, sugars, acid, pectin, esters, etc.) prove of little value as an index for appropriate maturity for harvesting. The investigation under report was, therefore, confined to the determination of firmness and colour of the fruit which have been found to be the best criteria [Allen, 1929] for harvesting pears, and on which depends the subsequent storage life of fruit for marketing as well as canning.

Material

In 1937, four random pear trees (William's variety) in an orchard, situated about half a mile from Kulu town, were reserved for this experiment. In 1938, another different lot of four pear trees of the same variety were similarly selected. The experiment was conducted on the spot at Kulu.

Experimental and methods

Fifteen random pears from each of the four trees (making a collective sample of 60 pears) were picked at five different intervals from 22 July to 9 August in 1937 and 26 July to 12 August in 1938. To determine the firmness of pears, ten random fruits from each lot were used for pressure tests, using a standard tester [Singh and Hamid, 1941] which measured in pounds the pressure required to force a plunger point 5/16th inch in diameter to a depth of 5/16th in. into the flesh of the fruit, the peel before testing being removed by the knife of the pressure tester. This ensured greater uniformity and accurate determination of the firmness of the flesh. Two tests were made on each fruit,

the points selected for each test were on opposite sides of the fruit at approximately the widest position of the cross-section and at right angles to the core.

TABLE I

Ripening of William's pears in Kulu valley in an orchard about half a mile from Kulu town (1937-38)

Date	Wt. of 60 pears		Average wt. of one pear	Pressure tests (pounds) average of 10 pears	Colour* index of fruit on picking	Number of days in storage at room temp. varying from 75°-80°F. for completion of canning trials	Condition† of ripened fruit before canning
(1937)	lb.	oz.	oz.				
22 July	23	0	6·13	16·3	1 to 1½	11—21	Very slight shrivelling, flat and poor flavour, colour unattractive
26 July	23	0	6·13	15·9	1 to 1½	10—16	No shrivelling, quality medium colour yellow
30 July	24	12	6·66	15·9	1½ to 2	9—14	No shrivelling, good flavour, yellow colour
3 August	25	12	6·87	13·8	2	8—12	No shrivelling, very good taste and flavour, attractive yellow
9 August	24	4	6·46	13·2	2 to 3	6—8	Ditto.
(1938)							
26 July	25	5	6·75	17·77	1½ to 2	7—9	Slightly raw flavour, no shrivelling
30 July	27	6	7·35	15·03	2	6—9	No shrivelling, full pear flavour and aroma., excellent colour
3 August	29	1	7·75	14·12	2 to 3	6—7	Ditto.
7 August	24	9	6·55	13·25	2½ to 3	4—7	Ditto.
12 August	23	10	6·30	12·37	3	5—7	Ditto.

* Details of colour index as used by Allen—No. 1, green ; No. 2, light green ; No. 3, yellowish green ; No. 4, yellow
† In all cases, colour index was No. 4 and lenticels prominently developed
NOTE—The fruit before canning, in all cases, had become soft and showed no pressure test

Average of 20 readings, thus obtained, was taken as a measure of firmness of the fruit. Colour of the fruit was determined by the aid of colour chart given by Allen [1929] and the method followed in comparing the colour of the fruit (at different stages of maturity) with the different colour indices designated as No. 1 (green), No. 2 (light green), No. 3 (yellowish green), No. 4 (yellow) was essentially the same as adopted by Allen [1929]. Where the colour of the fruit appeared to be between two shades, fractional numbers were used. The rest of the fruit from each lot after the above tests, was stored at room temperature (75°-80°F.) at Kulu. Pressure tests of various lots, the number of days from the time of picking when the fruits of each lot began to show ripening (canning trials were started at this stage), the total period of storage when the canning of each lot was finished, average weight of fruit, etc., are given in Table I. Variations in the pressure tests are graphically represented in Fig. 1.

As already mentioned, the fruit of each lot, as it attained the appropriate softness (yielded to a very slight pressure of thumb) and developed the characteristic pear 'aroma' and the proper yellow colour (index 4, Table I), was canned in 40° Brix sugar syrup by the method outlined by Lal Singh and Girdhari Lal [1941]. Ten different lots (Table I) of canned fruit as obtained in 1937 and 1938 were brought to Lyallpur and stored at room temperature and examined 4 times during a storage period of about 2 years in each case. 'Cut-out' tests were carried out by two or three individual observers in accordance with the score card

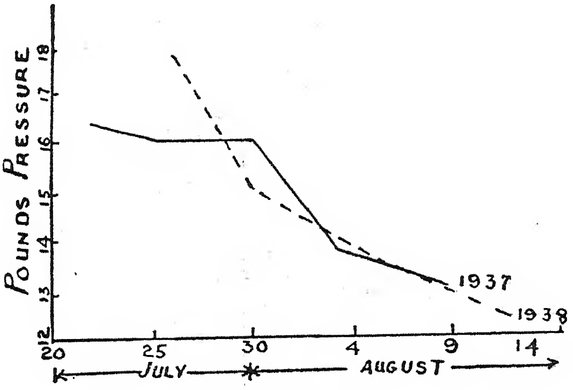

Fig. 1. Softening of William's pears in Kulu valley in an orchard at about half a mile from Kulu town (Years 1937-38)

system, given by Hirst and Adams [1932]. This 'Cut-out' technique involved a study of (*i*) cut-out strength of syrup, (*ii*) vacuum in cans, (*iii*) external and internal condition of can (*iv*), colour of contents, (*v*) condition of syrup, (*vi*) flavour and taste of contents, (*vii*) correct quantity of contents, (*viii*) condition of contents, and (*ix*) uniformity in grading. The above data as collected in a typical cut-out of the canned pears during storage are given in Table II. The entire data collected being voluminous are omitted for obvious reasons.

Discussion of results

A. *Changes in firmness of fruit, size, colour, etc.*

Pressure test for harvesting Bartlett pears as conducted by Allen [1929] in a number of orchards in U. S. A. for Eastern shipment varied, in general, from 19·0 to 23·0 lb. depending upon the locality. Similarly, Magness *et al.* [1929] determined the maturity of Bartlett pears from Pacific Coast Districts and found the pressure tests varying from 13·9 to 26·3 lb. (about 19·0 to 22·0 lb. being the best for commercial picking). These authors commenced their trials on maturity, long before the commercial picking season and hence found a wide variation in these tests—early fruit giving a higher figure and *vice versa*. During the present study conducted at Kulu, the tests, which were carried out just at the start of the commercial picking season, lasting over a period of about three weeks, showed a range of 13 to 18 lb. (Table I and Fig. 1). The Figures worked out in the U. S. A. for Bartlett pears and here in Kulu valley can hardly be expected to be of similiar magnitude as it is well recognized that the composition of fruit shows wide variations under different climatic conditions. Even in Kulu valley where the investigation was confined to only one locality, there was noticed a considerable variation in the harvesting time which differed from place to place because the topography of the valley is rolling with various exposures and elevations.

It is seen from Table I, that the weight and consequently the size of fruit, in general, tended to show an increase with the advance of season up to the begining of August and, thenceforth, there was a decline in their weight towards the end of the harvesting season unlike the increase in the softness of the fruit which was uniformly progressive with advance of season. Further, with the lateness in season, colour of the freshly picked fruit in accordance with the colour chart of Allen [1929] showed a gradual change in colour for No. 1 (green) to No. 3 (yellowish green). The lenticels or breathing pores were prominent in fruits of all pickings and seemed to have developed corky tissue which reduced transpiration losses.

B. *Maturity of fruit as related to canning*

A study of Table I shows that in summer 1937 the fruit had to be stored for a relatively longer period (varying from 6 to 21 days) after each picking before it properly ripened (colour index 4, Table I) and was fit for canning than in summer 1938 (period varying from 4 to 9 days), i.e. during the latter season the fruit ripened much more rapidly for canning purposes. This may be attributed to the differences in the climatic condition of these years, as the season of 1938 was relatively hotter and drier than 1937 summer.

Storage period required for fruit to attain proper softness and the desired yellow colour for canning decreased with the advance of season. Early picked fruit tended to show slight shrivelling during storage and the ripened fruit in this case was rather poor in quality. The quality of the store-ripened fruit improved with the advance in time of picking.

It will be seen from Fig. 1, that pressure tests during 1937 varied from 13 to 16 lb. and 12 to 18 lb. in the year 1938. 'Cut-out' tests carried out during the storage period of about 2 years on five lots (Table II) showed that the fruit picked at 13-14 lb. pressure yielded the best results on canning and such fruits were usually found picked in the first week of August in commercial harvests at Kulu.

Summary

(*i*) Firmness of William's pears grown in Kulu valley, Punjab, as determined by a standard pressure tester during the commercial harvests in 1937 and 1938, varied from 13 to 16 lb. and 12 to 18 lb. respectively.

(*ii*) 'Cut-out' tests on five lots of canned pears from each picking in 1937 and 1938, during a storage period of about two years, indicated that

TABLE II

'Cut-out' Tests on William's Pears, Canned in 40° Brix Sugar Syrup

Lot number	Date of picking	Pressure tests—average of 10 pears (lb.)	Date of cut-out tests	Cut-out strength of syrup at 63°F.	Vacuum in can (cm.)	External and internal condition of can	Colour of content	Condition of syrup	Flavour and taste of contents	Correct quantity of contents	Condition of content	Uniformity in grading	Total marks
						5	15	10	15	15	25	15	100
I	22 July 1937	16·3	7th Sept. 1938	26·7	...	4	9 dull white	9 clear	7 rather poor	12	15 hard and gritty	11	65
II	26 July 1937	15·9	7th Sept. 1938	25·4	10	4	8 dull white	9 clear	9 rather poor	11	13 hard and gritty	10	64
III	30 July 1937	15·9	7th Sept. 1938	26·0	8	4	9 dull white	9 clear	8 rather poor	11	13 hard and gritty	12	66
IV	3 Aug. 1937	13·8	7th Sept. 1938	24·8	15	4	12 light creamy yellow	9 clear	12 v. good	12	20 soft and mellow	12	77
V	9 Aug. 1937	13·2	7th Sept. 1938	25·6	11	4	12 light creamy yellow	9 clear	13 V. good	11	20 soft and mellow	13	79

the fruit picked at 13-14 lb. pressure, yielded the best results on canning and such fruits were usually found picked in the first week of August in commercial harvest at Kulu.

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STUDIES IN THE PRESERVATION OF FRUIT JUICES

IV. VITAMIN C (ASCORBIC ACID) CONTENT OF CITRUS FRUIT SQUASHES

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(With three text-figures)

The most important problem in the preparation of fruit products is the retention, as much as possible, of fresh fruit flavour. Second to the retention of flavour and colour is the retention of their nutritive value. Fruit juices have attained prominence in the human diet, particularly of growing children, largely as a source of water-soluble vitamins B complex and C and it is necessary that least deterioration in the nutritive value should be effected during the course of preparation and preservation of any kind of fruit juice product.

Citrus fruit juices being rich in vitamin C—the antiscorbutic vitamin, its determination in these juices has drawn the attention of quite a number of workers during recent years. Biological as well as chemical methods of its estimation have been found to give similar results. Davey [1921] showed that antiscorbutic vitamin of lemon juice was preserved at temperatures near freezing point by 0·06 per cent potassium meta-bisulphite but at higher temperatures destruction of vitamin occurred. It was later found [Delf, 1925] that five-sixth of the antiscorbutic potency of lemon juice was lost after 4½ years' storage, when 0·06 per cent potassium meta-bisulphite was present. William and Corran [1930] concluded that potassium meta-bisulphite was the best (of several including sodium benzoate) preservative for lemon juice, but it had deleterious effect on vitamin C at ordinary room temperatures. Bennet and Tarbet [1933] have recorded some interesting observations on the effect of different preservatives, addition of sugar, heating and pasteurization, etc., on the vitamin C content of lemon and orange juice during storage, and concluded that in untreated juice the reducing factor is protected from atmospheric oxidation by the action of an enzyme and that when this action is inhibited by any of the usual means, the reducing power is rapidly lost, least deterioration taking place when sulphur dioxide was used as a preservative. Joslyn *et al.* [1934] studied the relationship of browning of orange juice with its vitamin C content and concluded 'the extent of browning parallels the extent of loss in vitamin C so that either the latter is involved in browning or it is destroyed simultaneously'.

Very little information is available in the literature as to the extent of loss of antiscorbutic potency of sweetened juices (squashes, syrups, cordials, etc.) preserved in different manners except the work of Charley [1941] who determined the loss of vitamin C taking place during storage of syrups prepared and preserved under different manners for fruits like strawberry and black-currant.

The present study embodies the determination of changes taking place in the vitamin C content of orange and lemon squash of varying sugar concentrations preserved under different methods of preservation.

Material

Twenty-six sets of squashes of orange (Malta) and lemon (Eureka variety) with syrup densities

of 35°, 45° and 65° Brix in the finished product were chemically preserved with sodium benzoate (0·1 per cent), potassium meta-bisulphite (0·07 per cent) and pasteurization (at 185°-190°F.) for half an hour. Half of the above samples were prepared from freshly expressed juice and the other half from juice pre-heated to 87·5°C. for two minutes.

Methods of analysis

Tillman's method (titrating ascorbic acid with a standard solution of 2 : 6 dichlorophenol-indophenol) as developed by Bennet and Tarbet [1933] was applied to orange and lemon juice, but was found unsatisfactory on account of indefinite end-point of the titration. Tillman's method as modified by Birch, Harris and Ray [1933] and Ahmad [1935] was tried and found to give satisfactory results. The standard solution of the indicator (2 : 6 dichlorophenol-indophenol) was prepared by the method of Birch, Harris and Ray [1933] and standardized against pure ascorbic acid solution which in turn was standardized against 0·01 N. Iodine.

In the samples of orange and lemon squash preserved with sulphur dioxide, it was found that the presence of sulphur dioxide seriously interfered with the titration values for the indicator. Bennet and Tarbet [1933] and Downer [1941] suggest the removal of sulphur dioxide in a current of CO_2. No mention of the temperature, time and the mode of removal of SO_2 is made. Experiments were, therefore, undertaken with the natural juice containing sulphur dioxide to find the best method for driving away sulphur dioxide, and the results are presented in Table I.

The estimations of ascorbic acid were done in duplicate all through this investigation.

TABLE I

Effect of SO_2 on the ascorbic acid content of Malta orange juice

Sample No.	Treatment of juice	ml. of juice for 1·0 ml. indicator	Concentration of ascorbic acid in juice mg./100 ml.
1	Natural orange juice (immediately after extraction) . .	1·69	50·4 (Original concentration)
2	Juice in (1) with 0·07 per cent potassium meta-bisulphite .	1·35	63·0 (Value increased due to presence of SO_2)
3	Sample (2) evacuated on pump in air for 10 min. . .	1·68	50·6 (Restored to original value)
4	Sample (2) evacuated on pump in air for 20 min. . .	1·68	50·6 Ditto.
5	Sample (2) evacuated on pump in air for 30 min. . .	1·69	50·4 Ditto.
6	Sample (2) evacuated on pump in CO_2 for 10 min. . .	1·69	50·4 Ditto.
7	Sample (2) evacuated on pump in CO_2 for 20 min. . .	1·68	50·6 Ditto.
8	Sample (2) evacuated on pump in CO_2 for 30 min. . .	1·69	50·4 Ditto.
9	Sample (1) evacuated on pump in air for 10 min. . .	1·69	50·4 Ditto.

It will be seen from Table I that removal of sulphur dioxide under vacuum at a temperature of 100°-110°F. in a current of air or carbon dioxide restores the titration value of the juice containing sulphur dioxide, to the original value of the natural orange juice. Also, evacuation on pump in air for 10 min. does not affect the ascorbic acid value of the juice (item 9, Table I). An experiment, on similar lines as above, was conducted with samples of lemon and orange squash, separately, and results of similar nature were obtained. Hence the removal of sulphur dioxide by passing a restricted current of air under reduced pressure at a temperature of 100°-110°F. for 10 min. was effected in the samples of squashes containing sulphur dioxide.

It has, however, been recently claimed by Kirkpatrick [1941] that sulphur dioxide caused no interference with the dye titration, provided the end point was taken when the pink tinge persisted for 10 sec., a limit of even 30 sec. taken, introduced considerable error. On the other hand, Mapson [1942] found that sulphur dioxide in acid solution reduced the dye instantaneously and caused serious errors in the estimation of ascorbic acid in the case of vegetable extracts containing sulphur dioxide. In the method employed during the present study, the titration was concluded within 2-3 min. and the end point was taken when the pink colour persisted for a few seconds [Birch, Harris and Ray, 1933]. By this method also sulphur dioxide interfered in the titration values and had to be driven off as mentioned above.

Experimental

With the object of determining ascorbic acid content of different varieties of citrus fruits, 18 varieties of Malta (*Citrus sinensis* Osbeck), one variety of lemon (*Citrus limonia*) and two varieties

TABLE II

Ascorbic acid content of different varieties of citrus fruits—January-February 1938

Serial No.	Fruit	Variety	Mg. ascorbic acid per 100 ml. juice
1	Sweet orange (Malta orange)	Common (Lahore)	60·73
2	Do.	Common (Agra)	61·62
3	Do.	Valencia Late (Australia)	55·94
4	Do.	Common (Local)	72·47
5	Do.	Blood Red (Gujranwala)	54·51
6	Do.	Blood Red (Australia)	60·73
7	Do.	Blood Red (Lyallpur)	53·92
8	Do.	Ruby (Solon)	61·62
9	Do.	Vanielli	72·06
10	Do.	St. Micheal	55·21
11	Do.	Excellencis	62·13
12	Do.	Jaffa	58·12
13	Sweet orange	Musambi	56·65
14	Do.	Washington Naval	50·85
15	Do.	Dulcis	45·43
16	Do.	Duroi	53·28
17	Do.	Hamilin	72·19
18	Do.	Pine-apple	84·42
19	Lemon	Eureka	38·1C
20	Mandarin (*Sangtra*)	Common	25·50
21	Do.	Nagpuri	24·60

NOTE. Fruits under item 1 to 19 were obtained from the Experimental Garden, Lyallpur, and two varieties of *Sangtra* (items 20-21) were obtained from the local market

of *sangtra* (*Citrus nobilis*, Lour), were analysed, and the data obtained are recorded in Table II.

Wide variations in the ascorbic acid content of different varieties of Malta are of special interest. The ascorbic acid content varies from 45 to 84 mg. per 100 ml. in the juice of different varieties. In common Malta (plants imported from different sources) the ascorbic acid values vary from 60·73 to 72·47 mg. per 100 ml. of juice, in 'blood red' varieties, the minimum and maximum limits being 53·92 to 60·73 mg. per 100 ml. of juice. A great deal of variation is also observed in other varieties; lemon and *sangtra* giving comparatively low figures. Daniel and Rutherford [1937] carried out a similar survey of ascorbic acid content of different varieties of citrus fruit like orange, lemon, tangerine and grape fruit grown at different localities and found wide variations in the ascorbic acid values of different varieties and even in the same variety grown in different localities. They also found that 'Ruby blood' variety had much lower ascorbic acid content (37 mg. per 100 ml. of juice) than other varieties like Pine-apple, Hamilin, Washington naval, Valencia, etc.; their ascorbic acid values varying from 32 to 62 mg. per 100 ml. of juice. Ascorbic acid values of tangerine varieties varied from 18 to 24 mg. per 100 ml. of juice.

Since the 'Common' variety of Malta is a commercial variety in this Province, it was used for experiments on orange squash. Eureka variety of lemon, available in the Experimental Garden, Lyallpur, was used in lemon squash.

Methods used in the preparation of various sets of squashes were essentially the same as outlined by Lal Singh and Girdhari Lal [1938]. The analysis of the samples of juice employed in making these sets is given in Table III. Foot notes in this table give details of the peel emulsion added to fortify the flavour of squashes prepared.

TABLE III

Analysis of orange (Malta) and lemon juice used for making different sets of squashes (Tables IV and V)

Juice	Acidity as per cent citric acid	Degrees Brix at 63°F.	Sp. gr. of juice at 20°C.	Ml. juice for 1·0 ml. indicator	Ascorbic acid values mg./100 ml.
1. Orange (Malta) juice employed in lots A,B & C (Table IV)	0·55	8·86	1·035	2·23	45·43
2. Orange (Malta) juice employed in lots D & E (Table IV)	0·57	8·88	1·036	2·40	42·21
3. Lemon (European variety) juice employed in lots A & B (Table V)	4·85	7·97	1·030	3·24	31·25
4. Lemon (European variety) juice employed in lots C & D (Table V)	3·30	6·43	1·026	3·23	31·4

N.B.—(1) Peel of 4·0 per cent fruits used for juice extraction was thoroughly ground and strained through thick cloth and incorporated in the juice

(2) To incorporate peel oil in the squash, one-fourth of the lemons used were separately sliced and crushed in a basket press and the extracted juice was mixed with the rest of the juice (extracted in the ordinary manner)

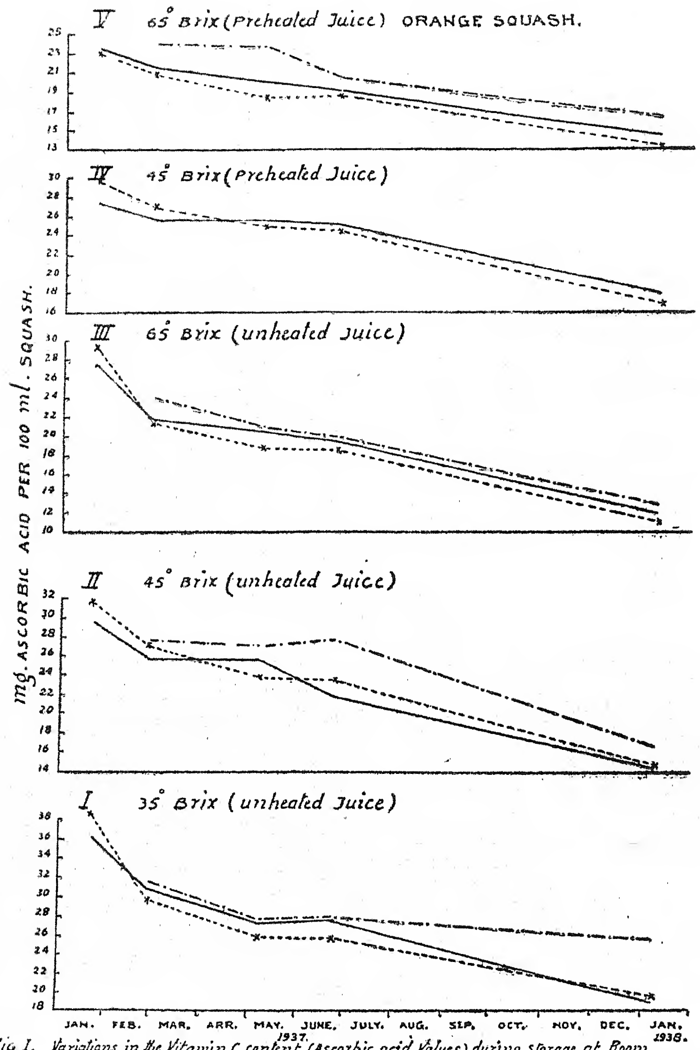

Fig. I. Variations in the Vitamin C content (Ascorbic acid Values) during storage at Room temperature, of orange squash with different concentrations of sugar in the finished product under various methods of preservation.

——— SQUASH PRESERVED WITH 0·1 PERCENT SODIUM BENZOATE.
×---×---× SQUASH PASTEURIZED AT 185°-190° F FOR 20-30 MINUTES.
—·—·— SQUASH PRESERVED WITH 0·07 PERCENT POTASSIUM METABISULPHITE.

Ascorbic acid values of orange squash (A to E—35° to 60° Brix) determined at varying intervals during storage from 21 January 1937 to 7 January 1938 are given in Table IV. Unheated juice was employed in lots A to C, whereas in lots D and E, juice which had been heated at 87·5°C. for 2 min. was employed for making the squash. Joslyn and Marsh [1934] suggest that in order to destroy pectic enzymes involved in the clearing and clumping of juice, it must be heated to 87·5°C. for 2 min. or for 8 min. at 85°C. In order to see whether this pre-heating of juice in any way affected the vitamin C content of squash, the above method was also adopted in addition to the usual method of preparation of a squash.

Similar data, as collected in the case of orange squash, have been given for lemon squash in Table V, except that squash with 35° Brix syrup strength was not prepared in this case. The results given in Tables IV and V are graphically represented in Figs. 1 and 2, respectively. A clear picture of the losses of vitamin C in these sets can be obtained from Table VI in which the percentage decrease of ascorbic acid values during the first five weeks, succeeding 11 months' storage, and ultimate total loss are given. The losses during the (1) and (2) periods (Table VI) are graphically represented in Fig. 3.

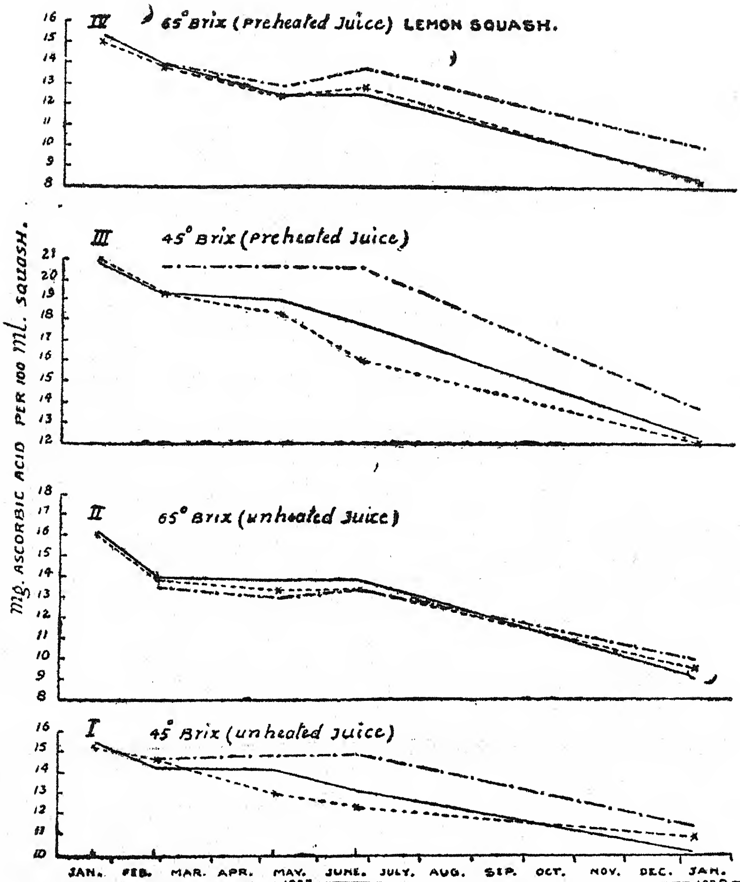

Fig. 2. Variations in the Vitamin C content (Ascorbic acid Values) during Storage at Room temperature; of Lemon Squash (European Variety) with different concentrations of Sugar in the finished product under Various methods of preservation.

——— SQUASH PRESERVED WITH 0·1 PERCENT SODIUM BENZOATE.

-x-x- SQUASH PASTEURIZED AT 185°-190° F FOR 20-30 MTS.

-·-·- SQUASH PRESERVED WITH 0·07 PERCENT POTASSIUM METABISULPHITE.

Ascorbic acid losses in orange and lemon squash

Brief account of the results of experimental data presented above have been reported in the Annual Progress Reports of the Fruit and Vegetable Preservation Scheme (1937-38). Detailed considerations regarding the loss of ascorbic acid content in orange and lemon squash during storage, as elucidated by the data obtained are briefly discussed below.

(*i*) *Effect of different methods of preservation*

It is well known that all kinds of fruit and vegetable products during storage deteriorate in quality and their vitamin content. Davey [1921], Delf [1925] and William and Corran [1930], while determining the loss of antiscorbutic potency of lemon juice, showed that vitamin C showed a decline of varying degree under different conditions of preservation and storage. A loss of ascorbic acid content of similar nature in sweetened lemon and orange juice of varying degree, under different treatments is observed from the data presented in this publication. The ascorbic acid values per 100 ml. of orange and lemon squash in all treatments, show a decline (Figs. 1 and 2) which is comparatively more pronounced in samples of squash either preserved with sodium benzoate or pasteurization, decrease in ascorbic acid values being the least in samples of squash preserved with sulphur dioxide. The pasteurized squash loses its ascorbic acid at about the same rate as that treated with benzoic acid. Decrease in ascorbic acid values is much more rapid during the first five weeks of storage than the loss taking place in the latter part of the storage period (Figs. 1, 2 and 3). During one

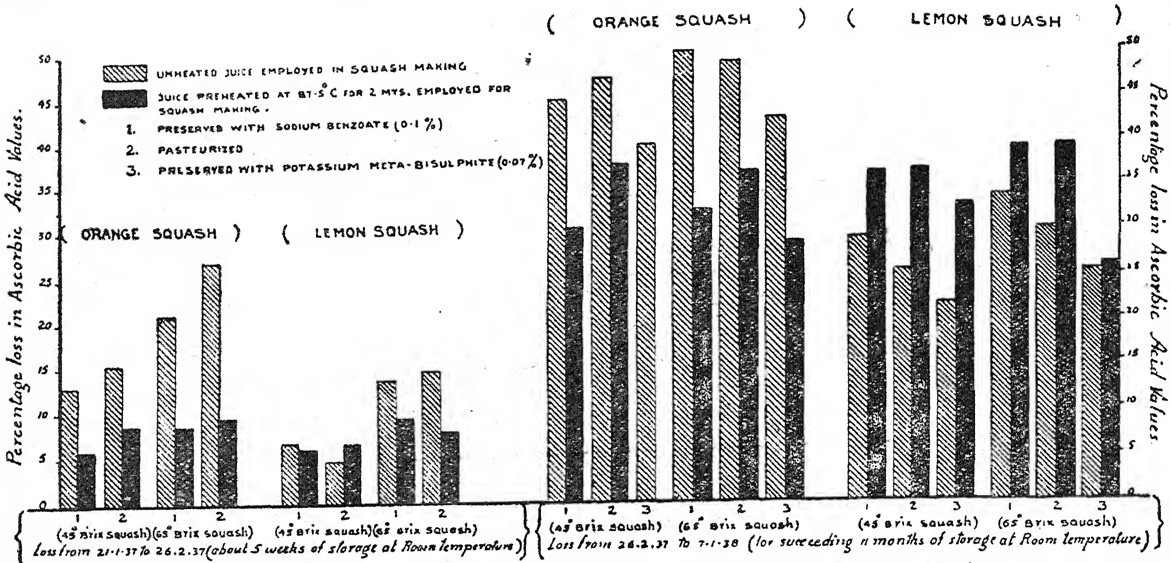

Fig 3. Percentage loss in Ascorbic acid Values during different periods of storage of ORANGE SQUASH and LEMON SQUASH (Varying concentrations of sugar in the finished product and packed under different methods of preservation) in which unheated juice and the juice preheated to 87·5°C for 2 mts. was employed.

TABLE IV

Ascorbic acid content of orange squash during storage

(mg. ascorbic acid/100 ml. of squash)

Lots	Date	Preserved with 0·1 per cent sodium benzoate	Pasteurized at 185-190°F. for 20-30 min.	Preserved with 0·07 per cent potassium metabisulphite	Remarks
A (35° Brix)	21-1-1937	36·18	38·81	..	Unheated juice used for lots A, B and C
	26-2-1937	30·77	29·62	31·53	
	6-5-1937	27·25	25·72	27·49	
	24-6-1937	27·52	25·79	27·90	
	7-1-1938	18·90	19·41	24·71	
B (45° Brix)	21-1-1937	29·62	31·85	..	
	26-2-1937	25·72	26·96	27·44	
	6-5-1937	25·58	23·70	27·06	
	24-6-1937	21·83	23·55	27·68	
	7-1-0938	14·17	14·29	16·55	
C (65° Brix)	21-1-1937	27·52	29·36	..	
	26-2-1937	21·72	21·42	23·96	
	6-5-1937	20·30	18·62	20·78	
	24-6-1937	19·33	18·38	19·75	
	7-1-1938	11·83	10·92	13·72	
D (45° Brix)	21-1-1937	27·45	29·62	..	Pre-heated juice (heated at 87·5°C. for 2 min.) used for lots D and E
	26-2-1937	25·81	26·97	..	
	6-5-1937	25·45	24·86	..	
	24-6-1937	25·07	24·59	..	
	7-1-1938	17·96	16·85	..	
E (65° Brix)	21-1-1937	23·61	23·02	..	
	26-2-1937	21·55	20·80	24·05	
	6-5-1937	Spoiled	18·36	23·81	
	24-6-1937	14·08	18·66	20·55	
	7-1-1938	14·60	13·20	16·39	

TABLE V

Ascorbic acid content of lemon squash during storage

(mg. ascorbic acid/100 ml. of squash)

	Date	Preserved with 0·1 per cent sodium benzoate	Pasteurized at 185-190°F. for 20-30 min.	Preserved with 0·07 per cent potassium metabisulphite	Remarks
A (45° Brix)	21-1-1937	15·49	15·35	..	Unheated juice for lots A & B
	26-2-1937	14·43	14·64	14·59	
	6-5-1937	14·07	12·97	14·76	
	24-6-1937	13·05	12·40	14·94	
	7-1-1938	10·21	10·90	11·41	
B (65° Brix)	21-1-1937	16·16	16·13	..	
	26-2-1937	13·96	13·77	13·47	
	6-5-1937	13·86	13·36	13·0	
	24-6-1937	13·99	13·54	13·53	
	7-1-1938	9·23	9·62	10·05	
C (45° Brix)	21-1-1937	20·69	20·76	..	Pre-heated juice (at 87·5°C. for 2 min.) employed for lots C and D
	26-2-1937	19·45	19·36	20·63	
	6-5-1937	18·97	18·40	20·59	
	24-6-1937	17·90	16·10	20·59	
	7-1-1938	12·38	12·23	13·84	
D (65° Brix)	21-1-1937	15·35	15·06	..	
	26-2-1937	13·92	13·84	13·76	
	6-5-1937	12·50	12·51	12·79	
	24-6-1937	12·63	12·91	13·86	
	7-1-1938	8·48	8·38	10·21	

year's storage, total loss in the ascorbic acid values (all treatments) varies from about 38 to 62 per cent in orange squash and about 30-45 per cent in lemon squash. Final acidity of samples of lemon squash and orange squash was about 2·5 per cent and 1·5 per cent (in terms of citric acid), respectively. Higher acidity of lemon squash seems to have comparatively a better protective influence on its antiscorbutic potency than the less acid orange squash which shows more deterioration in its vitamin content.

It would appear, therefore, that sulphur dioxide is comparatively a better preservative towards vitamin C in citrus fruit squashes than pasteurization and sodium benzoate [Annual Progress Report, 1938]. Later, Charley [1941] also reported that both in strawberry and black-currant syrups, sulphur dioxide acted as a definite preservative towards vitamin C, while pasteurization and benzoate additions were much less satisfactory means of preserving the vitamin as compared with sulphur dioxide treatment. Bennet and Tarbet [1933] reported results of similar nature in the case of orange and lemon juice (plain and sweetened with 40 per cent cane sugar) preserved by similar methods, but reported that the reducing power of these even in the case of SO_2 disappeared within 30-40 days which is a much faster rate of loss than that found in the present study. They have further made a tentative suggestion that in orange juice, ascorbic acid was retained in the presence of sulphurous acid to a greater extent than in lemon juice. This again is contradictory to the results presented in the present study in which magnitude of losses of ascorbic acid in orange squash under all treatments are greater than in the case of lemon squash.

(ii) Effect of pre-heating the juice

A very interesting phenomenon in the behaviour of orange and lemon squashes prepared from unheated and pre-heated juice is noticed from the losses of ascorbic acid during 11 months' storage (Table V). During first five weeks of storage (Fig. 3) the differences in the ascorbic acid losses in the samples prepared from pre-heated and unheated juice are not so marked, but during succeeding 11 months, there is definitely more loss of ascorbic acid in the squash prepared from pre-heated juice than that prepared from the unheated juice. It will be seen that in orange squash, irrespective of all treatments, the product prepared from the pre-heated juice, shows less deterioration in its vitamin C (ascorbic acid) content than that

TABLE VI

Percentage loss of ascorbic acid in orange squash and lemon squash during storage (Tables IV and V)

Period	35° Brix						45° Brix						65° Brix					
	Preserved with sodium benzoate		Pasteurized		Preserved with sulphur dioxide		Preserved with sodium benzoate		Pasteurized		Preserved with sulphur dioxide		Preserved with sodium benzoate		Pasteurized		Preserved with sulphur dioxide	
	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated	Un-heated	Pre-heated
Orange qsuash																		
(1) 21 January 1937 to 26 February 1937 (about one months storage)	14·9	...	23·7	...	...	...	13·2	5·97	15·3	8·94	...	...	21·1	8·72	27·0	9·64	...	...
(2) 26 February 1937 to 7 January 1938 (about 11 months' storage)	38·6	...	34·5	...	21·6	...	44·9	30·4	47·0	37·5	39·7	...	50·1	32·2	49·0	36·5	42·7	28·9
(3) Total loss from 21 January 1937 to 7 January 1938 (one year's storage)	47·8	...	50·0	...	...	...	52·2	43·6	55·1	43·1	...	...	57·0	38·2	62·8	42·7	...	...
Lemon squash																		
(4) Period as in (1) above	...	...	...	...	...	...	6·84	6·0	4·63	6·7	...	...	13·6	9·3	14·6	8·1	...	...
(5) Period as in (2) above	...	...	...	...	...	...	29·2	36·3	25·5	36·8	21·8	32·9	33·9	39·1	30·1	39·4	25·4	25·8
(6) Period as in (3) above	...	...	...	...	...	...	34·1	40·1	29·0	41·1	...	...	42·9	44·7	40·3	44·4	...	...

prepared from un-heated juice. In lemon squash, however, this process seems to be reversed.

Loss of ascorbic acid presented in Fig. 3 can be summarized as :

	Orange squash	Lemon squash
Unheated juice . .	More loss	Less loss
Heated juice . .	Less loss	More loss

At first sight, it appears that a fairly simple explanation can be given by assuming that the volume of dissolved air in the case of orange juice is greater than in lemon juice and brings about a greater loss of ascorbic acid in the unheated juice than in the heated one, where it is eliminated by heating. Comparing this with the heated lemon juice, the lesser amount of dissolved air must naturally be expected to produce less loss of ascorbic acid. On the contrary, there is more loss. This explanation has, therefore, to be ruled out and another sought for.

In plant tissues, the destruction of ascorbic acid is either (*i*) oxidative, and is caused by the action of air alone or when they are heated in contact with air, and (*ii*) enzymatic, due to the action of vitamin C (ascorbic acid) oxidase or ascorbase, if present, the destructive action of which is inhibited by heat. Althoug hcitrus juices do not have any appreciable quantities of ascorbase [Cruess, 1938] it is, nevertheless, easy to conceive of the presence of amall quantities of ascorbase in the case of orange juice and absence in lemon juice. Therefore, in orange squash prepared from pre-heated juice, the ascorbase will be inactivated by heat, thus, inhibiting its destructive action on vitamin C. This inactivation of ascorbase brings about comparatively smaller losses of ascorbic acid in the heated juice. In lemon squash, however, pre-heating appears to introduce purely oxidative changes, due to the action of heat and air, thus resulting in an accelerated loss of ascorbic acid as compared with the loss in unheated juice.

(*iii*) *Effect of syrup strength*

It will be seen from Fig. 3 and Table VI that, in general, lemon and orange squashes with high sugar syrup strength (65° Brix), irrespective of methods of preservation, have a tendency to lose more ascorbic acid than the squash with lower sugar content (45° Brix). Losses are more pronounced when unheated juice is employed for making either of the squashes.

High sugar concentration in preserved foods is known to exert a definite preservative action against spoilage due to moulds, yeast, etc., but it seems to be not so effective in conserving the vitamin C of the squashes in storage, the high ascorbic acid values being associated with low sugar content. Charley [1941] observed rather high loss of about 64 per cent of vitamin C in concentrated black-currant juice (juice concentrate 7 : 1). No explanation has been offered by him for this abnormal loss. This high loss may have been due to increased concentration of sugar in the concentrates, as has been observed during the present study in case of squashes with high sugar content. Griebel and Hess [1942] on the basis of their experiments on rose-hip and black-currant jams, suggest that 'a high sugar content is an important factor in preserving the ascorbic acid content of foods'. They, however, do not give a clear conception of the comparative effect of different concentrations of sugar on the vitamin content of foods.

The author takes this opportunity to thank Sardar Bahadur Lal Singh, Fruit Specialist, Punjab, for his advice and criticism during the course of this investigation. He expresses his indebtedness to the Imperial Council of Agricultural Research for the research grant under which this study was carried out.

Summary

1. Changes in the ascorbic acid values of orange (Malta) squash and lemon squash with different sugar syrup strengths (35°, 45° and 65° Brix) preserved with sodium benzoate, sulphur dioxide and pasteurization, have been studied during a storage period of one year.

2. Direct titration method of Tillman with 2 : 6 dichlorophenol-indophenol as modified by Birch, Harris and Ray [1933] has been satisfactorily employed for determining ascorbic acid values.

3. Sulphur dioxide was found to seriously interfere with the titration value for the dye and was satisfactorily driven off under reduced pressure in a current of air at 100°-110°F.

4. Preservation with sulphur dioxide was comparatively more effective in conserving the vitamin C content of orange and lemon squashes than the addition of sodium benzoate or pasteurization.

5. Orange squash, irrespective of methods of preservation, etc., showed more losses in ascorbic acid than lemon squash, during a storage period of about one year.

6. In orange squash, pre-heating the juice, irrespective of methods of preservation and sugar concentration, has a protective influence on the ascorbic acid value, which may be due to the presence of some amount of ascorbic acid oxidase in orange juice which is inactivated by the action of heat, whereas in lemon squash, pre-heating the juice adversely affected its ascorbic acid content, the action being probably 'oxidative' in this case.

7. During storage period of about one year, high sugar syrup strength (65° Brix) in lemon and orange squash, particularly, in unheated juice, has a comparatively more destructive action on the ascorbic acid values than lower sugar concentration (45° Brix).

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REVIEWS

Bacteria in Everyday Life. By M. R. Madhok. *(Published by Dr M. R. Madhok, Punjab Agricultural College and Research Institute, Lyallpur, 1942 pp. 74, Re. 1-8)*

THIS is a handy booklet dealing with the different aspects of bacteria in everyday life. The contents include interesting chapters on the origin and scope of bacteriology, bacteria in agriculture, bacteria in arts and industries, important bacterial diseases, their causes and cure and so on. The book is written in a simple language and should prove to be useful to the students of agricultural colleges and other interested in the subject. The get-up is as good as can be expected.—S.C.R.

***Phalon ki kheti or babosai* (Third Edition),** By N. T. Vyas. (*Published by the Manager, Leader Press, Allahabad, 1942, pp. 233, Re. 1-10*)

THE book covers in its 11 chapters all the different aspects of fruit culture and presents the importance of the fruit industry and the possibilities of commercial orcharding in India. Important items of orchard management dealing with the selection of site, cultivation, suitable layouts, manuring, methods of propagation, after-care, the occurrence of diseases and pests and their control have all been properly dealt with in a lucid and simple style.

The previous editions of the book were very well received all over the country and it is certain that the present edition will continue to prove as useful as the previous ones. It has already been recognized as a text-book for the agricultural schools in different provinces and should prove to be of considerable value to all interested in fruit culture. It is certainly a most useful addition to the limited vernacular literature available on agricultural subjects.—S.C.R.

GIPD—3S—471 IC of AR—30-11-43—600.

ORIGINAL ARTICLES

STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

XII. FURTHER EXPERIMENTS ON THE AMELIORATION OF *TIRAK**

By R. H. Dastur,† Mukhtar Singh and Sucha Singh, Punjab Agricultural College, Lyallpur

(Received for publication on 29 June 1943)

The importance of June sowing as an ameliorative measure for *tirak*, occurring on the two soil types, viz. sandy loam with saline subsoil and light sandy soil deficient in nitrogen, has already been demonstrated by Dastur and Mukhtar Singh [1942; 1944]. It was also pointed out that the application of sulphate of ammonia on the former soil type was a total failure, whereas its use on the latter was highly effective. There are, however, lands where both the *tirak*-promoting soil-conditions co-exist. Light sandy soils deficient in nitrogen are also found to contain saline or alkaline subsoil A brief reference to *tirak* amelioration on such fields must be made, before further evidence on the success of the three ameliorative measures, namely, nitrogen, water and late sowing, under the different soil conditions, is presented and discussed.

Investigation

A. Amelioration of tirak

A field, where the worst form of *tirak* was observed in the cotton season of 1937 was selected at the Lyallpur Agricultural Farm for experimentation. The mechanical analysis of the soil showed that it generally contained about 76 per cent of sand in the upper 2 ft. At places, the sand was as high as 80 per cent on the surface and seedlings died soon after germination on such spots. The third and the fourth feet had comparatively lower percentage of sand. The sand fraction, however, increased again from the fifth foot, till it was practically all sand below.

The chemical analyses revealed the presence of varying amounts of sodium clay at different depths. Wherever sodium clay was present in the upper 2 ft., the growth of plants was stunted.

Over major portion of the field, plants made good growth up to August, when they began to show symptoms of nitrogen starvation, i.e. yellowing and reddening of leaves. The bearing was normal, but the individual bolls were so imperfect in development on account of the aggravating influence of adverse subsoil that nearly 1000 bolls were required to give 1 lb. of *kapas*.

At some places, the plants became stocky with short internodes. The leaves turned copper-coloured, curled upwards forming cups. On examination such leaves showed large quantities of starch in the mesophyll cells. The flowers appeared in clusters at the tips of the fruiting branches. The bolls formed were small containing highly immature seeds. Solitary flowers continued to be produced till late in the season, but they were usually shed. The examinaiion of the root system of such plants, on this field, showed vigorous main and secondary roots that were devoid of fine rootlets, the chief absorbing organs. The rootlets, however, were produced in large numbers, but they died soon after appearance leaving dark coloured scars at the points of emergence. It is highly probable that sodium clay with unfavourable *pH* in the subsoil was responsible for the above symptoms on these isolated patches.

A factorial experiment was laid out on this field in 1938 with the object of finding out the ameliorative effect, if any, of the three factors, namely, nitrogen, potash and the application of extra presowing irrigations. The last treatment was included to create subsoil reserve of water. The treatments comprised all combinations of:

Nitrogen	*Potash*	*Water*
o=No manure	*o*=No potash	*o*=No presowing waterings
g=Green manure berseem at 20 tons per acre	*k1*=120 lb. K_2O per acre	*w*=Two presowing waterings
m=Farmyard manure at 20 tons per acre	*k2*=240 lb. K_2O per acre	
n=Amm. sulphate at 90 lb. N per acre	*k3*=360 lb. K_2O per acre	

*This work was done in the Punjab Physiological (Cotton Failure) Scheme financed jointly by the Indian Central Cotton Committee and the Punjab Govt.

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A basal dressing of 80 lb. P_2O_5 per acre, in the form of superphosphate double, was given to all plots as a precautionary measure. As the soil was heterogeneous it was necessary to confound partially some of the high-order interactions. Block size was reduced to 8 plots instead of 32. Two complete replicates were provided.

Observations made during the season revealed similar behaviour of the plants, as already described for the previous cotton crop, with the difference that yellowing and reddening of leaves did not develop in the nitrogen-treated plots. Besides, the application of nitrogen encouraged vegetative growth, improved bearing and raised the yields but there was no amelioration of *tirak* (Table I). The increase in yield under nitrogen-application, therefore, resulted only from increased bearing. Neither potash nor presowing waterings were of much avail in the reproductive or the vegetative phase.

TABLE I

Treatment effects on the developmental characters and the yield—1938-39 experiment

(Light sandy soil with saline subsoil)

Treatment	Height per plant in cm.	Number of bolls per plant	Boll weight in gm.	Yield in lb. per 100 plants
No manure	96·4	26·2	1·219	5·41
F. Y. manure	116·3	32·9	1·332	8·40
Green manure	115·4	36·4	1·137	7·12
Ammonium sulphate	108·9	32·4	1·294	7·97
S. E.	±*3·93*	±*2·68*	±*0·089*	±*0·76*
No potash	106·9	32·3	1·199	6·36
Potash I	111·2	35·8	1·250	7·52
Potash II	108·0	28·8	1·226	7·11
Potash III	110·9	31·0	1·307	7·91
S. E.	±*3·93*	±*2·68*	±*0·089*	±*0·76*
Ordinary watering	109·9	31·0	1·197	6·76
Two extra presowing waterings	108·6	32·9	1·294	7·69
S. E.	±*2·78*	±*1·90*	±*0·063*	±*0·54*

1939-40

An experiment was conducted in the succeeding season in an adjoining piece of land under more or less similar conditions of the soil as described under the previous experiment. The aim was to confirm the previous findings and to explore the effects of the late sowing on *tirak* and the yield on the same theoretical grounds that governed its success on either of the two *tirak* soils. To obtain further evidence as to the dependence of late sowing on close spacing, the factor of spacing was also introduced. In addition to 4F, a *desi* short-stapled variety, known as Mol. 39, was included.

There were three replicates under the experiment. To the main plots were allocated 8 combinations of: two sowing dates ($d1$=6-5-39, $d2$=10-6-39), two varieties (4F, Mol. 39) and two levels of inorganic fertilizer mixture [control vs. (50 lb. P_2O_5 + 50 lb. K_2O) per acre applied on 4 August]. The main plots were split for two levels of nitrogen (control 25 lb. N per acre applied on 4 August) and each plot thus formed accommodated two spacing types ($s2$=2 ft. × 3 ft., $s1$=2 ft. × $1\frac{1}{2}$ ft.). Thus the layout was a split-plot design.

All the main effects and the significant interactions on the basis of the statistical analyses of the data collected from this experiment are given in Tables II to V, and are discussed below.

It is evident from Table II that there was a substantial increase in yield by the sowing, mainly through improvement in the opening of bolls and partly through increased bearing. Nitrogen did not ameliorate *tirak* but affected boll number favourably and thereby the yield. Significant effects of P+K and of spacing on boll number were not reflected in yield and should be reckoned to have arisen by chance. Mol. 39 outyielded significantly the 4F Punjab-American because greater number of bolls of the former matured normally. In the case of 4F, not only were the bolls fewer in number but they were also affected by *tirak*. It is to be noted that the normal boll size of *desi* cotton is about 1·5 gm. and of 4F nearly 2 gm.

TABLE II

Main effects—1939-40 experiment

(Light sandy soil with saline subsoil)

Treatments		Number of bolls per sq. yard: Mean	Diff. ±S. E.	Boll weight in gm.: Mean	Diff. ±S. E.	Yield of *kapas* in md. per acre: Mean	Diff. ±S. E.
Sowing date	*d1*	64·13	+8·09*±3·121	1·178	+0·433**±0·062	9·59	+4·02**±0·535
	d2	72·22		1·611		13·61	
Varieties	*4F*	52·57	+31·22**±3·121	1·323	+0·143*±0·062	8·88	+5·44**±0·535
	Mol. 39	83·79		1·466		14·32	
Phosphorus and potash	*o*	62·81	+10·75**±3·121	1·380	+0·029±0·062	11·18	+0·84 ±0·535
	pk	73·56		1·409		12·02	
Nitrogen	*o*	61·01	+14·34**±4·189	1·357	+0·076±0·046	9·94	+3·32**±0·319
	n	75·35		1·433		13·26	
Spacing	*s1*	73·25	—10·14**±3·406	1·382	+0·025±0·030	11·71	—0·22 ±0·261
	s2	63·11		1·407		11·49	

The differential behaviour of sowing dates with nitrogen (or of nitrogen with dates), is shown in Table III. In the absence of nitrogen, the effect of late sowing on yield was specially high because boll size as well as boll number increased. In the presence of N, boll size improved by delayed sowing but there was no effect on boll number and, therefore, the effect in yield was of a lower order. The maximum yield was, however, recorded under *d2n*.

TABLE III

Interaction : Sowing date × nitrogen—1939-40 experiment

(Light sandy soil with saline subsoil)

Number of bolls per sq. yd.			Boll weight in gm.			Yield of *kapas* in md. per acre		
	d1	*d2*		*d1*	*d2*		*d1*	*d2*
o	51·69	70·34	*o*	1·132	1·581	*o*	7·55	12·33
n	*76·59*	*74·11*	*n*	*1·224*	*1·641*	*n*	*11·63*	*14·88*
Diff : ±5·92	+24·90**	+3·77	Diff : ±0·066	+0·092	+0·060	Diff : ±0·45	+4·08**	+2·55**
D. N. =	—10·56*	±4·189	D. N. =	—0·016	±0·046	D. N. =	—0·76*	±0·319

The relation between sowing date and spacing is brought out in Table IV. Early-sown crop produced the same number of bolls at both the spacings provided, but a great increase in boll number occurred under late-sown crop spaced close. This effect appeared as a significant interaction on boll number and was simultaneously reflected in yield. Boll weight, however, improved by late sowing irrespective of the spacings.

N.B.—In all the tables of this paper,*=significant at 5 per cent level of significance and **=significant at 1 per cent level of significance

TABLE IV

Interaction : Sowing date × spacing—1939-40 experiment

(Light sandy soil with saline subsoil)

Number of bolls per sq. yd.			Boll weight in gm.			Yield of *kapas* in md. per acre		
	d1	*d2*		*d1*	*d2*		*d1*	*d2*
s1 (close)	64·27	82·22	*s1* .	1·169	1·595	*s1* .	9·14	14·28
s2 (wide)	*64·00*	*62·22*	*s2* .	*1·187*	*1·627*	*s2* .	*10·04*	*12·94*
Diff : ±4·817 .	—0·27	—20·00**	Diff : ±0·042	+0·018	+0·032	Diff : ±0·370	+0·90*	—1·34**
D. S. =	—9·86**	±3·406	D. S. =	+0·007	±0·030	D. S. =	—1·12**	±0·261

The two varieties did not respond equally to nitrogen (Table V). The response in the case of Mol. 39 was distinctly greater. It may again be noted that the source of increase in yield through N-applications was the boll number component alone and not the boll weight. Briefly stated, on light sandy soil with saline subsoil, the improvement in boll opening, through late sowing, was the same irrespective of the nitrogen level and the spacing adopted. But the yield response to delay in sowing varied in magnitude to the extent the boll number component was influenced, under the varying levels of the other factors. Nitrogen did not raise the boll weight, though some gain in yield resulted from increased bearing.

TABLE V

Interaction : Variety × nitrogen—1939-40 experiment

(Light sandy soil with saline subsoil)

Number of bolls per sq. yd.			Boll weight in gm.			Yield of *kapas* in md. per acre		
	4F	Mol. 39		4F	Mol. 39		4F	Mol. 39
o .	49·91	72·11	*o* .	1·289	1·424	*o* .	7·55	12·33
n .	*55·22*	*95·47*	*n* .	*1·358*	*1·508*	*n* .	*10·21*	*16·31*
Diff : ±5·92	+5·31	+23·36**	Diff : ±0·066	+0·069	+0·084	Diff : ±0·45	+2·66**	+3·98**
V. N. =	+9·02*	±4·189	V. N. =	+0·007	±0·046	V. N. =	+0·66	±0·319

B. Trials of the ameliorative measures

It could be inferred from the foregoing results and those aready published [Dastur and Mukhtar Singh, 1942; 1944] that late sowing as a measure for ameliorating *tirak* and maintaining or increasing yields was of general application while the response to N (or water) was primarily governed by soil conditions.

The evidence in support of the above findings was obtained from experiments conducted at Lyallpur with 4F Punjab-American cotton. Obviously, it was necessary to test them, on a wider basis, by laying out similar large-scale experiments in the different cotton-growing tracts in the Punjab, using the commonly-cultivated variety of American cotton of each tract. Apart from the trial of the three successful ameliorative measures alluded to, it was considered desirable to include, in such an experimental programme, one *desi* variety (Mol. 39) and more than one American strains. The extent to which the different varieties would respond to the ameliorative measures, particularly late sowing, could thus be explored.

It can scarcely be doubted that the ultimate test of the soundness or economics of a

measure is its trial under actual *zamindari* conditions. It is possible that the results obtained under standard agricultural practices may not hold good on cultivators' fields. Moreover, experiments on the *zamindars'* farms are of special value inasmuch as these farms serve as centres for disseminating information and form the nucleus of improvement. The experiments reported below were, therefore, mainly conducted on the farms of *zamindars* during the years 1940-1942.

1940-41

Description of experiments. The first series of confounded designs with subplot arrangement were laid out concurrently at Brucepur (Lyallpur), B.C.G.A. Farm, Khanewal (Multan), Convillepur (Montgomery), and the New Seed Farm, Sargodha. All combinations of four sowing dates, two watering types (normal and heavy) and two levels of nitrogen (o. 33 lb. N per acre) were tried in six blocks of eight plots each, confounding completely with block differences the second-order interaction D.W.N.

Levels:	($c1$=Spare) ($c2$=Thorough)	×	($4F$) (*Mol. 39*)	×
Factors;	Priliminary cultivation		Variety	

with six-fold replication. There were three restrictions on the randomized block arrangement, viz. (1) C.V.W. was completely confounded with block differences, (2) combinations of cultivation and variety lay in array strips, and (3) the array strips were split longitudinally into two substrips each, for the two sowing dates. The final size of the experimental subplot was 1/80 acre.

The other experiments at Lyallpur had four levels of nitrogen (o, 16 lb. N, 32 lb. N, 48 lb.N) as the main-plot treatments, in six blocks. By simultaneous double-splitting, the main plots were subdivided longitudinally into three strips, for three sowing dates ($d1$=10-11 May, $d2$ = 28-29 May, $d3$ = 15-16 June) and transversely into four plots for four varieties (4F, LSS 289F/43, Mol. 39). The allocation of varieties to the transverse plots was random, with the restriction that sets of variety × nitrogen interactions were partially confounded with the transverse rows and balanced arrangement attained. At picking, the experimental subplot was 1/100 acre. The different types of soils were represented in these experiments. The nature of soil conditions under each experiment is stated along with the presentation of its results.

Treatment effects on the opening of bolls. Statistical analysis of the boll weights in the first series of experiments revealed that the linear response to dates was highly significant in case of all the three experiments, viz. Brucepur, Khanewal and Convillepur. The quadratic response appeared only at Convillepur. Sowing dates interacted with varieties whose mean boll sizes also varied widely. The main effect of nitrogen and its interaction with varieties came out significant only at Convillepur. The nature of effects for the individual experiments has been illustrated below by summary tables. Boll weights were not recorded at Sargodha.

Three or four varieties were accommodated in each main plot, as mentioned below:

Brucepur	Khanewal	Convillepur	Sargodha
289F/43	289F/43	289F/43	289F/43
LSS	K25	K25	LSS 4F
Mol. 39	Mol. 39	Mol. 39	Mol. 39

The size of the subplot after rejection of borders, was nearly 1/60 to 1/40 acre in the different experiments. Heavy watering was secured by rewatering the plots, to be so treated, 18-24 hours after the normal irrigation to all plots. Differentiation in irrigation started after manuring in August. Watering types had to be dropped at Convillepur (Montgomery) on account of good rains in August and September.

The respective sowing dates for the different experiments are given in parentheses in the tables of results.

The second set of experiments were conducted at the Lyallpur Agricultural Farm. One of the experiments studied all combinations of:

($w1$=3 week) × ($w2$=Fortnight)	×	($d1$=18-20 May) ($d2$=20 June)
Watering interval, during fruiting		Sowing date

It is evident from Table VI that at Brucepur better development of bolls was attained in the third and the fourth sowings. The increase was particularly marked in the Americans. The response to heavy watering was small and suggestive and to nitrogen insignificant.

The effectiveness of late sowing in mitigating *tirak* was still more pronounced at Khanewal (Table VII). There was a progressive increase in the weight of seed cotton per boll with every delay in sowing, in the case of the American strains. K25 was particularly benefited inasmuch as its boll size nearly doubled by 1½ months' delay in sowing. Mol. 39, on the other hand, maintained its boll size at the normal level in all the sowings. The higher mean boll size in *desi* as compared with the Americans, at Khanewal and Brucepur, was due to the fact

TABLE VI

Treatment effects on boll weight in gm. at Brucepur

(Sandy loam with saline subsoil)

	Dates / Varieties	*d1* (8/5)	*d2* (24/5)	*d3* (8/6)	*d4*(24/6)	*Mean*	
Dates (linear)=1·11**±0·32	289F/43	1·29	1·52	1·78	1·67	1·57	±0·029
Dates (quadratic) =—0·224±0·144	LSS.	1·42	1·58	1·90	1·68	1·65	
Watering=0·126±0·072	Mol. 39	1·58	1·64	1·72	1·82	1·69	
Nitrogen=0·015±0·072	Mean ±0·072	1·43	1·58	1·80	1·73	..	

that the former escaped *tirak* while the latter suffered greatly under early sowings.

At Khanewal also nitrogen applications were ineffective in raising the boll weight on account of salinity in the subsoil.

The effect of delayed sowings in increasing the size of the bolls was equally marked on light sandy non-saline soil of the Convillepur experiment (Table VIII) even though *tirak* was practically absent in the early sowing also. The boll size of 289F/43 improved considerably by late sowing while the response in case of Mol. 39, though progressive and proportionate, was smaller in magnitude. K25 behaved in a slightly different manner inasmuch as the highest boll weight was attained at the third sowing. Rains incidentally following irrigations during August and September induced jassid attack in K25. The damage was relatively greater in the later sowings and more so in the presence of nitrogen. It is remarkable that in spite of this disadvantage K25 produced the best boll under *d3*. The decline under *d4* influenced the mean boll weight of this variety and also accounted for the significance of the quadratic response to dates.

TABLE VII

Treatment effects on boll weight in gm. at Khanewal

(Light sandy soil with saline subsoil)

—	Dates / Varieties	*d1* (13/5)	*d2* (28/5)	*d3* (14/6)	*d4* (27/6)	Mean	
Dates (linear) =1·96**±0·36	289F/43	1·16	1·29	1·66	1·78	1·47	±0·05
Dates (quadratic)=—0·116±0·16							
Watering =0·076±0·08	K25	1·09	1·45	2·00	2·12	1·66	
Nitrogen =—0·051±0·08	Mol. 39	1·74	1·79	1·78	1·75	1·77	
	Mean ±0·08	1·32	1·51	1·81	1·88	..	

TABLE VIII

Treatment effects on boll weight in gm. at Convillepur

(Light sandy non-saline soil)

Dates / Nitrogen	*d1* (8/5)	*d2* (23/5)	*d3* (7/6)	*d4* (22/6)	Mean	Dates / Varieties	*d1* (8/5)	*d2* (23/5)	*d3* (7/6)	*d4* (22/6)	Mean	
o	1·76	2·28	2·30	2·31	2·16	289F/43	2·05	2·59	2·57	2·68	2·47	±0·049
n	2·15	2·28	2·44	2·30	2·29	K25	1·96	2·31	2·52	2·12	2·22	
						Mol. 39	1·86	1·94	2·02	2·11	1·98	
Diff. ±0·087	0·39**	...	0·14	—0·01	...	Mean ±0·043	1·96	2·28	2·37	2·30	...	
Mean response to N=0·13**±0·043						Dates (linear)=1·14**±0·19						
						Dates (quadratic)=—0·19**±0·043						

The sandy character of the soil at Convillepur was also conductive to a well marked response to nitrogen application. On further analysis of the data it is seen that highly significant increase with nitrogen was restricted to the plots of the first sowing only. The decline in response to nitrogen with the advancing sowing dates is to be expected on light sandy soils as already pointed out in a previous contribution [Dastur and Mukhtar Singh, 1944]. It is probable that greater jassid attack on nitrogen-treated plants of the later sowings might also have inhibited any small improvement that would otherwise have occurred with N in the later sowings.

The first experiment at Lyallpur which aimed at exploring the effect of frequent irrigations in addition to that of late sowing with reference to the two varieties (4F, Mol. 39) clearly demonstrated the effectiveness of either of the two measures on a soil with a saline subsoil (Table IX). The relative importance of each measure, however, varied with the varieties. Heavy irrigation was efficacious only in the case of 4F, while late sowing helped Mol. 39 to a greater extent.

TABLE IX

Treatment effects on boll weight in gm. at Lyallpur

(Sandy loam with saline subsoil)

$d2—d1 = 0{\cdot}20^{**} \pm 0{\cdot}033$

$w2—w1 = 0{\cdot}22^{**} \pm 0{\cdot}062$

$4F—Desi = 0{\cdot}32^{**} \pm 0{\cdot}101$

$V.\,D. = 0{\cdot}08^{*} \pm 0{\cdot}033$

$W.\,V. = —0{\cdot}138^{*} \pm 0{\cdot}062$

Varities	4F		Mol. 39	
Dates / Watering	d1 (18/5)	d2 (20/6)	d1 (18/5)	d2 (20/6)
w1	1·60	1·85	1·41	1·68
w2	2·08	2·08	1·47	1·77
Diff.	0·48 **	0·23 **	0·06	0·09

$D.\,V.\,W = 0{\cdot}068 \pm 0{\cdot}038$

TABLE X

Treatment effects on boll weight in gm. at Lyallpur

(Light sandy soil with alkaline patches)

Dates / Nitrogen	d1 (10/5)	d2 (28/5)	d3 (15/6)	Mean ±0·091
o	1·66	1·61	1·83	1·70
16 lb. N	1·60	1·65	1·84	1·70
32 lb. N	1·67	1·76	1·82	1·75
48 lb. N	1·81	1·84	1·91	1·85
Mean ±0·019	1·68	1·71	1·86	..

Dates / Varieties	d1 (10/5)	d2 (28/5)	d3 (15/6)	Mean ±0·038
4F	1·44	1·47	1·60	1·50
289F/43	1·98	1·97	2·07	2·01
LSS	1·89	1·83	2·05	1·92
Mol. 39	1·43	1·55	1·71	1·56
Mean ±0·019	1·68	1·71	1·86	..

The evidence furnished by the second experiment at Lyallpur (Table X) points to the conclusion already reached that the later the sowing, the better the boll size. June sowing was significantly superior to the two May sowings which did not differ among themselves. All the four varieties responded equally to late sowing. The magnitude of increase with late sowing, however, was not very high in this experiment, due to the presence of alkalinity in the surface foot in big patches over considerable area of the field. For the same reason, the effect of nitrogen which was kept as main-plot treatment was not demonstrable in this experiment.

The effects of sowing date, nitrogen and watering on yields. The results of yields under different treatments were not identical with those already discussed above for the opening of bolls, as yields depend not only on the size of bolls but also on their number. Increase in boll size is not always associated with increase in boll number. In fact, the two may even be negatively correlated, in which case quality gains at the expense of quantity.

The trends of yield under the four sowing dates were of two types. Either the linear response to dates was significant or there was a significant departure from the linear. In the latter case the combined yield of the second and the third sowings was significantly better than that of the first and the fourth. The following points should be borne in mind before considering the mean responses to dates: (1) Close spacing adopted for the fourth sowing did not prove adequate on very light sandy soils or those possessing saline patches near the surface. Consequently the boll number decreased considerably in the last sowing. (2) The inclusion of Mol. 39 in most of the experiments subdued the mean response to sowing date as all sowings under this variety behaved alike and did not show any yield trend with advance in sowing dates. (3) The American varieties also differed to the extent to which they lent themselves for late sowings. In some cases, the order of their suitability for delayed sowing was the same as the order of their resistance to jassids (*Empoasca devastans*). Since 1940-41 was a relatively wet year, jassid attack was much pronounced on some of the varieties. (4) Watering and nitrogen treatments also modified the mean response to sowing date, as May-sowings profited more by these treatments than June-sowings. These effects will be indicated by significant interactions between sowing date and other factors.

The results of the individual experiments require to be considered for a comprehensive study of the effect of sowing time and its relation to other treatments. The actual dates of sowing are given in parentheses in each case.

The results for Sargodha (Table XI) revealed that optimal values for sowing date were obtained at the third sowing in case of L S S and 4F. The yield of 289F/43, however, was maintained at a uniformly low level as far as the second week of June. The yields fell off in the case of all Americans in the last sowing. Mol. 39, on the other hand, kept up its yield at a high level over the entire sowing period. L S S gave the highest mean yield of the three Americans irrespective of sowing dates, and its superiority became more and more marked as the sowing was delayed till the optimum date.

Nitrogen increased the yield significantly on account of the sandy character of the soil under the experiment at Sargodha and the response to N varied with the varieties. They responded in the order of their yielding capacity, viz. Mol. 39 > L S S > 4F > 289F/43. The response also differed with the sowing dates. Only the first two sowings gave substantial increases in yield through nitrogen application.

TABLE XI

Treatment effects on yield (md. per acre) at Sargodha

(Light sandy and saline)

Dates / Varieties	d1 (15/5)	d2 (30/5)	d3 (15/6)	d4 (30/6)	Mean ±0·45
289F/43	5·37	5·87	5·81	2·56	4·90
L.SS	8·53	10·17	12·64	5·19	9·13
4F	7·00	8·30	8·79	3·19	6·82
Mol. 39	17·19	18·09	16·41	17·27	17·24
Mean	9·52	10·61	10·91	7·05	..

Nitrogen / Varieties	o	n	Diff. ±0·946
289F/43	4·79	5·01	0·22
L. S. S.	7·95	10·31	2·36*
4F	6·08	7·56	1·48
Mol. 39	15·24	19·24	4·00**
Mean	8·52	10·53	..

Dates / Nitrogen	d1	d2	d3	d4	
o	8·09	8·68	10·21	7·09	8·52
n	10·96	12·53	11·62	7·01	10·53
Diff. ±1·06	2·87*	3·85**	1·41	—0·08	..

Dates (linear) = —7·11** ± 2·38
Dates (quadratic) = —4·94** ± 1·06
Nitrogen = 2·01** ± 0·53
Watering = 0·65 ± 0·53

At Brucepur (Table XII) all varieties gave the highest yields under the third sowing. The yield increased rapidly with delay in sowing in L S S. As increase in 289F/43 through late sowing proceeded slowly, the differences in yield between L S S and 289F/43 widened as the sowing was delayed. Beyond the third sowing, decline in yield occurred, but this decline was steeper in case of 289F/43 and is to be attributed to excessive curtailment in the

grand period of growth of this early-maturing variety. In such cases, particularly, the spacing provided turned out to be inadequate on account of the limited growth made by the plants.

TABLE XII

Treatment effects on yield (md. per acre) at Brucepur

(Sandy loam with saline subsoil)

Dates / Varieties	d1 (8/5)	d2 (24/5)	d3 (8/6)	d4 (24/6)	Mean ±0·52	Watering / Varieties	w1	w2	Diff. ±1·33
289F/43 . .	8·78	9·72	10·69	5·89	8·77	289F/43 . .	8·09	9·44	1·35
LSS . . .	9·63	12·52	15·93	10·34	12·10	LSS . .	10·94	13·26	2·32
Mol. 39 . .	24·93	24·25	25·68	22·85	24·42	Mol. 39 . .	21·81	27·03	5·22**
Mean . . .	14·44	15·49	17·43	13·02	..	Mean . .	13·62	16·58	..

Boll number per sq. yard	d1	d2	d3	d4	
Mean ±2·60	71·7	65·4	66·6	47·3	Dates (quadratic) = —5·46* ± 2·05; Watering = 2·96** ± 1·02; N = 1·15 ± 1·02

The varieties responded to watering in the order of their yield capacity, viz. Mol. 39 > LSS > 289F/43. Nitrogen did not give significant increase in yield nor did it interact with any other factor, because of the saline subsoil.

It is evident from a study of Table XIII for Convillepur (Montgomery) that quadratic response to dates was highly significant, since the central sowings were revealed to be optimum on the whole. Besides, varieties exhibited marked differential behaviour in relation to sowing date. It is remarkable that 289F/43 adapted favourably to late sowing. Mol. 39 behaved indifferently. The yield of K25 could not be maintained beyond the third sowing date and this was the direct outcome of reduction in bearing caused mainly by a heavy jassid attack on K25, as already explained. The behaviour of K25 in the Montgomery tract is analogous to that of 289F/43 at Lyallpur and Sargodha.

TABLE XIII

Treatment effects on yield (md. per acre) at Convillepur

(Light sandy soil)

Dates / Varieties	d1 (8/5)	d2 (23/5)	d3 (7/6)	d4 (22/6)	Mean ±0·36	Nitrogen / Varieties	o	n	Diff. ±0·821
89F/43 . .	12·09	16·11	16·40	12·43	14·26	289F/43 . .	13·09	15·43	2·34**
K25 . . .	10·23	12·49	10·87	4·76	9·59	K25 . .	9·44	9·74	0·30
Mol. 39 . .	22·10	24·61	20·85	22·22	22·44	Mol. 39 . .	19·55	25·33	5·78**
Mean . . .	14·81	17·74	16·04	13·14	..	Mean . .	14·03	16·84	..

No. of bolls per sq. yard	d1	d2	d3	d4	
Mean	68·5	63·5	61·6	46·0	Dates (linear) = —6·71* ± 2·55; Dates (quadratic) = —5·83** + 1·14; N = 2·81** ± 0·57

The soil being light and sandy the main effect of N was significant at Convillepur. Varieties did not respond equally to nitrogen application. Maximum advantage accrued to Mol. 39, medium to 289F/43 and none to K25 (Table XIII). The order of response conformed to the order of yield performance. The failure of any increase in case of K25 on light sandy soil is explicable in terms of severe jassid attack under nitrogen treatment counterbalancing any good that would otherwise have accrued as a result of manuring.

TABLE XIV

Treatment effects on yields (md. per acre) at Khanewal

(Sandy loam with saline subsoil)

Dates / Varieties	*d1* (13/5)	*d2* (28/5)	*d3* (14/6)	*d4* (27/6)	Mean ±0·49	Nitrogen / Varieties	*o*	*n*	Diff. ±0·976
289F/43	6·95	7·26	9·26	12·26	8·93	289F/43	8·54	9·33	0·79
K25	9·06	10·85	11·54	11·72	10·79	K25	10·40	11·18	0·78
Mol. 39	21·71	22·20	22·66	25·44	23·00	Mol. 39	21·12	24·87	3·75**
Mean	12·58	13·44	14·48	16·47	..	Mean	13·35	15·13	..
	d1	*d2*	*d3*	*d4*					
w1	11·05	12·09	14·02	16·11	13·32	Dates (linear) = 12·73** ± 2·46			
w2	14·10	14·79	14·93	16·83	15·16	N = 1·77** ± 0·55			
Diff. ±1·10	3·05**	2·70*	0·91	0·72	..	W = 1·84** ± 0·55			

The effect of late sowing was the most marked at Khanewal (Multan) where the relation between yield and sowing date was positive and linear (Table XIV). The yield rose progressively with delay in sowing in all the varieties bringing out an optimum at the last date. The magnitude of increase was also substantial.

The response to nitrogen application at Khanewal confined itself only to the *desi* variety, which gave the maximum yield on the average. The Americans failed to respond on account of salinity in the soil. Response to watering was recorded and it declined in magnitude with the delay in sowing (Table XIV).

The experiment designed to study the effect of more frequent irrigations and late sowings at Lyallpur (Table XV) established the need for more waterings at fruiting. Early-sown 4F profited the most in conformity with the previous experience.

Substantial increases in yield, through nitrogen applications were recorded on the light sandy soil under the second experiment at Lyallpur (Table XVI). The effectiveness of nitrogen did not fall off in the higher doses. The highest dose, of course, was only 48 lb. N per acre. The last sowing was less responsive to nitrogen than the first two which benefited to the same extent practically.

TABLE XV

Treatment effects on yields (md. per acre) at Lyallpur

(Sandy loam soil with saline subsoil)

Varieties	4F		Mol. 39		
Dates / Watering	*d1* (18/5)	*d2* (20/6)	*d1* (18/5)	*d2* (20/6)	
w1	11·62	13·16	18·91	20·67	C = —0·39 ± 1·16
w2	19·97	17·96	22·77	25·88	D = 1·10 ± 0·83
					W = 5·55** ± 0·92
					V = —6·38** ± 1·16
Diff.	8·35	4·80	3·86	5·21	D. V. W. = 1·23* ± 0·45

The last sowing date proved optimum at lower levels of nitrogen (o, 16 lb. N) while the central sowing gained importance at higher levels (32 lb. N, 48 lb. N). The effect of sowing time also varied with the varieties, 4F and LSS responding favourably to delay in

TABLE XVI

Treatment effects on yield (md. per acre) at Lyallpur

(Light sandy soil with alkaline patches)

Dates / Varieties	d1 (10/5)	d2 (28/5)	d3 (15/6)	Mean ±0·239	Dates / Nitrogen	d1 (10/15)	d2 (28/5)	d2 (15/6)	Mean ±0·842
4F	7·15	7·80	8·78	7·91	Control	7·90	8·40	9·27	8·52
289F/43	9·40	9·49	7·52	8·80	16 lb. N	8·98	9·58	9·99	9·52
LSS	9·72	11·27	10·70	10·56	32 lb. N	10·64	11·94	11·43	11·34
Mol. 39	14·53	15·60	16·01	15·38	48 lb. N	13·27	14·24	12·30	13·27
Mean ±0·188	10·20	11·04	10·75	..	Mean ±0·188	10·20	11·04	10·75	..

sowing. As at Brucepur, LSS showed the best performance amongst the Americans under each sowing individually, and especially so under the later sowings.

1941-42

Similar effects of late sowing, as discussed in the preceding pages, with respect to the opening and the yields of American cottons, were revealed by multiple-factor experiments conducted during 1941-42. These experiments were laid out at the Military Farm, Okara, B.C.G.A. Farm, Khanewal, the Departmental Agricultural Farms at Montgomery and Multan, and S.B.S. Ujjal Singh's Farm at Mian Channu. June sowings gave higher boll weights than May sowings irrespective of the varieties. The yield results were also favourable. It is not necessary to discuss the results of the individual experiments in detail here, but a few interesting features merit consideration. A new promising strain, 289F/124, evolved by the Cotton Research Botanist, Lyallpur, for the dry districts of the Punjab, was included along with other varieties in some of the experiments. It can be seen from Table XVII that this variety behaved remarkably well under late sowing both at Montgomery and Multan. It is necessary to point out that at Lyallpur 289F/124 is generally a failure when sown in June because of reduction in bearing caused by subnormal growth and jassid attack and inability of this variety to cover the soil surface under these conditions.

TABLE XVII

Effect of late sowing in relation to variety on boll weight and yield

Dates / Varieties	Montgomery (1941-42)						Multan (1941-42)		
	Boll weight (gm.)			Yield (md. per acre)			Yield (md. per acre)		
	d1 (15/5)	d2 (8/6)	d3 (24/6)	d1 (15/5)	d2 (8/6)	d3 (24/6)	d1 (19/5)	d2 (6/6)	d3 (24/6)
289F/43	1·81	2·03	2·09	10·11	10·98	9·75	11·65	12·45	13·49
289F/K25	1·22	2·16	1·91	7·73	10·11	7·87	10·04	12·12	12·66
289F/124	1·23	2·28	2·01	9·19	14·71	11·39	9·52	11·99	16·34
Mean	1·42	2·16	2·00	9·01	11·93	9·67	10·40	12·19	14·61
S.E.	±0·0596			±0·42			±0·598		

The weather conditions in Multan and Montgomery are generally different from those at Lyallpur and were specially so in the year under report (1941-42). The months of September and October were characterized by unusual spells of higher temperatures than normal in the south-western district so much so that *tirak* appeared in a serious form in the early sowings under adverse soil conditions, and even spread to areas mediumly saline in the subsoil. Lyallpur, however, experienced mild temperatures and abundant rains during

August and September, and October too was not unusually warm. Owing to the favourable weather, the May sowings in the experiments at Lyallpur matured their bolls normally, in spite of the saline subsoil. This resulted in the absence of any increase in yield due to deferred sowing even though the variety used was 4F (Table XVIII). It is noteworthy, however, that the yield did not fall under June sowing. Similarly it has been observed that on rich non-saline lands where the opening of bolls is normal irrespective of sowing date, June sowing is as good as May sowing, provided the spacing is close enough under the former.

TABLE XVIII

Effect of late sowing on 4F at Lyallpur (1941-42)

(Sandy loam soil with saline subsoil)

	d1 (21/5)	*d2* (23/6)	Remarks
Yield (md. per acre)	18·16	18·65	Differences non-
Boll weight (gm.) .	2·70	2·75	signifiant

C. Extensive trial of late sowing on a commercial farm (1940-41)

To set up late sowing on a practical basis it was necessary to test it on a field scale. B.C.G.A. Farm, Khanewal, was the first commercial farm that took the lead in this direction and offered cooperation to try out this measure extensively. The sowings on this farm used to start in the first week of May and finished by the end of this month. The crop was frequently subject to intense *tirak* and the yields were generally much below expectation. Since 1940, May sowings have been practically abandoned in favour of June sowings, with encouraging results. A record yield of 15 md. per acre was obtained over an area of 1,500 acres in 1940-41. In the following season, in spite of the very unfavourable weather at boll development, in the form of a hot and dry spell, from the end of September to the middle of October, damaging the crops in the districts of Montgomery and Multan, the average yield at the Khanewal Farm was 10 md. per acre. In 1942-43, the sowings were again done according to the schedules (given later) but due to unusual rains in the first week of July, some of the fields had to be resown and sowings completed by the middle of July. Nevertheless, the average yield was 16½ md. per acre.

To get an idea of the actual benefit accruing from the adoption of this measure, a simple but replicated sowing-date experiment with K25 variety was also arranged at the B.C.G.A. Farm, Khanewal, in 1940 and repeated in the two succeeding seasons. Twelve strips of land of two acres each under uniform cropping were selected each year, and the choice was extended over a number of squares of a *chak* which was different in different years. Each strip was divided into four half-acre plots, and the four dates of sowing were allocated at random to them. Each plot was picked and weighed separately so that the result could be statistically analysed. There was remarkable similarity from year to year, in the yield trend of the different sowings, in spite of the wide variations in the level of yields and the character of the soil and the season. June sowings were consistently better than extreme sowings and the highest yield was obtained from the crop sown about 20 June (Table XIX).

DISCUSSION

In addition to ameliorating *tirak*, the yield of *kapas* can also be increased and maintained by June sowing, provided closer and closer spacing is adopted with advancing sowing dates in June and due consideration is given to the choice of variety. The relation of spacing with sowing date has been fully discussed in the

TABLE XIX

Effect of late sowing on the yield of cotton at the B. C. G. A. Farm, Khanewal, for three successive seasons (1940-42)

(Yield in maunds per acre)

Year	Site	Area	*d1* (19-22 May)	*d2* (4-7 June)	*d3* (19-22 June)	*d4* (5-7 July)†	S. E.
1940-41 . .	Chak 75	24 acres	12·62	14·48	16·10	14·92	±0·62
1941-42 . .	Chak 83	24 acres	5·38	6·47	7·06	5·77	±0·406
1942-43 . .	Chak 81-82	20 acres	9·50	14·87	15·49	8·58†	±0·912

† Resown on 15 July due to rains

previous contributions [Dastur and Mukhtar Singh, 1942; 1943] and is in accord with the experience of other workers on cotton in the Sudan [Gregory *et al.*, 1932; Lambert and Crowther, 1935]. Schedule A gives an idea of the changing seed rates and spacings with advancing weeks in sowing period, and has been prepared from practical point of view to suit the Punjab conditions.

Schedule A

Date of sowing	Seed rate to be used per acre	Distance to be kept between rows	Distance to be kept between plants
25—31 May . . .	7—9 sr.	2½ ft. to 3 ft.	1½ ft.
1—7 June . . .	8—10 sr.	2½ "	1¼ "
8—15 June . . .	10—12 sr.	2 "	1¼ "
16—23 June . . .	12—14 sr.	2 "	1 "
24—30 June . . .	14—16 sr.	1½ "	9 in.

The differential behaviour of variety with sowing date is the outstanding feature of this investigation. 289F/43 variety in the Lyallpur and Sargodha districts and K25 in the Montgomery district do not do well when sown after 15 June on account of a marked decrease in their boll number under these conditions. K25 and 289F/124 behave still worse under June sowings at Lyallpur. On the other hand, LSS in Lyallpur and Sargodha, 4F in Lyallpur, 289F/43 in Montgomery and Multan, and 289F/K25 and 289F/124 in Multan respond favourably to delay in sowing. These varieties are popular with the cotton growers in their respective localities and this renders the adoption of late sowing in general practice easy. The superiority of a variety adapted to a particular tract becomes better and better marked as sowing is delayed till the optimum date which is usually in the second week of June. Under earlier sowing, however, the Americans do not differ so widely.

The cause for the better adaptability of certain varieties to late sowing is to be sought in their ability to make sufficient growth so that the bearing capacity does not suffer appreciably. Besides, as already pointed out in a previous contribution [Dastur and Mukhtar Singh, 1942], the varieties that are susceptible to jassids, e.g. K25, 289F/124, have an earlier optimum under conditions inducing jassid attack, as compared with others that are relatively jassid resistent, e.g. LSS, 289F/43 and 4F. Where jassid attack is non-existent, K25 and 124F do admirably well under late sowings.

A cultivator is unable to sow all his cotton in a single day. Sowings have got to be distributed over two, three or even four weeks, depending upon the availability of water, sowing facilities and method of sowing. In practice, therefore, we have to decide upon the optimum sowing period rather than the optimum sowing date. Thus sowings must extend on either side of the optimum date as revealed by experiments, and varieties chosen should be appropriate as they vary in their suitability for late sowing.

The absolute range of sowing period for different localities is different, even if the right variety is used in the right place. As the primary reason for advocating late sowing is to maintain water balance of the plant under conditions of physical or physiological drought or both, it is natural that such a practice becomes indispensable in drier parts, viz. Multan and dry parts of Montgomery. In such places the sowings can extend as far as the beginning of July, because of the long spell of hot and dry weather which proves disastrous for early sowings. In districts where wet summers are more frequent, e.g. Sargodha and Sheikhupura, delay beyond the middle of June in years of heavy rainfall is exposed to danger of jassids. But early sowings have got to be avoided on account of danger of *tirak* in certain years and under certain soil conditions. At such places the rule should be to start late, sow quick and plant thick. For localities such as Lyallpur and Jhang which occupy intermediary position as regards the distribution of rain, the sowing period also lies mid-way between the two extremes. Schedule 'B' gives in a concise form an idea of the optimum sowing periods based on the above considerations.

In the early years of introduction of American cottons in the Punjab, the general sowing time was the month of March, which was then shifted to April gradually. In later years the month of May has been recognized to be the

Schedule B

Districts	Best sowing period	Variety
Sargodha, Sheikhupura	25 May—15 June	LSS
Lyallpur, Jhang	25 May—20 June	LSS and 4F (43F, if sown, should be completed before 15 June)
Montgomery	25 May—25 June	K25 and 43F (K25 should not be sown after 15 June)
Multan	1 June—5 July	K25, 43F, and 124F

Note.—Light sandy soils or soils of low fertility should, in practice, be sown in the first fortnight of the sowing periods recommended in the schedules, as further delay in sowing on such lands is apt to increase boll size at the cost of boll number and thus cause reduction in yield

optimum period. As a result of the recent investigations into the *tirak* problem the superiority of June sowings has definitely been brought out. It can thus be conceived why failure years concentrated in the 10-year period 1919-1928 and the crops failed miserably in 1919, 1920, 1921, 1926, 1927 and 1928.

It appears that American cottons, to start with, came to be sown about the same date as was prevalent in case of the indigenous short-stapled cottons. The sowings were then early and seem to be induced by the availability of water at the termination of the *rabi* season. Besides, the abundant growth made by such sowings gave the misleading impression of correlated high yields. These factors, rather than any direct evidence, popularized the tendency for early sowings. The practice may not have been as bad in the case of *desi* as of Americans because the former are able to mature their bolls and maintain yields over a wide range of sowing period. The Americans, with the sowings in vogue at that time, undoubtedly, suffered greatly under certain soil and climatic conditions.

The interplay of soil conditions with the weather factors governs the intensity and spread of *tirak* in a particular year. Under the influence of favourable weather, the crop on certain fields potentially subject to *tirak*, may actually escape its onslaught, even though sown in May. There can thus be wide variations in the yield of cotton on such fields from year to year. The benefit that can be expected to accrue from late sowing, will like-wise vary. The usefulness of this measure on a particular soil in a particular year will be great or small depending upon the decrement in the boll weight of the early-sown crop from the normal.

The differential response of varieties to nitrogen is another important finding of this experiment. It is noteworthy that the response order of the varieties is also the order of their yielding capacity. Similar relation has been recorded for varieties in Egypt by Crowther *et al.* [1937].

Desi (Mol. 39) responds the most everywhere. LSS is seen to respond better than 289 F/43 in Lyallpur and Sargodha. 289F/43 is better suited for manuring than K25 in Montgomery on account of the latter's known susceptibility to jassids, particularly under N-fed conditions. It is, however, possible that 289F/43 and K25 may not differ so widely in their response to nitrogen in a non-jassid year.

Watering has been effective in most of the experiments where salinity was present in the subsoil. As with nitrogen, the response to water has been great or small in the different varieties according to their yield.

The declining responses to nitrogen and water with advancing sowing dates suggest a rational discrimination in the use of additional water or nitrogen if available. The first sowings within the sowing range stated in Schedule 'B', should receive preferential treatment for extra watering on fields with saline subsoils, and for nitrogen on light sandy non-saline lands.

The differential behaviour of the three ameliorative treatments under the three soil types can be condensed in the form of a table (Table XX) which is self-explanatory.

Obviously, the maximum benefit can only be derived when the right remedy is applied in the right place. It is not normally possible for a *zamindar* to distinguish the soil conditions causing *tirak*. Besides, soils with saline or normal subsoil are intermingled. The practice of late sowing obviates the study of soil conditions and is, therefore, of wider applicability. As the adoption of this measure involves no extra cost, any increase in yield, great or small, is a net gain.

TABLE XX

Relative magnitude of the ameliorative effect of water, nitrogen and late sowing on the three soil types

	Sandy loams with saline subsoil	Light sandy and saline	Light sandy
Extra water	High response on opening and yield	Medium response on opening and yield	Low response on opening and yield
Nitrogen	No response on opening and yield	No response on opening but medium to low response on yield due to an increase in boll number	High response on opening and yield
Late sowing with close spacing and under ordinary water supply	High response on opening and yield	High response on opening and yield	High response on opening and low to medium response on yield

SUMMARY

This paper embodies the results of numerous multi-factor experiments in relation to *tirak* disease of cotton conducted in the different cotton-growing tracts of the Punjab over a number of years with the commonly-cultivated varieties.

Applications of nitrogen and extra water are specific remedies. Extra water at the fruiting stage ameliorates *tirak* and gives higher yields of *kapas* on soils with saline subsoil, where nitrogen application is totally ineffective.

Application of nitrogen is highly successful in reducing *tirak* and raising yields on light sandy non-saline soils, where the response to heavy watering is meagre.

On soils which are not only sandy and deficient in nitrogen but are also saline or alkaline in the subsoil, the application of nitrogen does not improve opening of bolls even though it raises the yield through more profuse bearing.

June sowing is a common ameliorative measure irrespective of the *tirak*-promoting soil conditions. The commonly-cultivated American cottons are prone to *tirak* when sown in May, but they improve in opening when sown in June. The yield results are also favourable, provided the necessity of close spacing for late sowing is correctly appreciated.

As it is extremely difficult for a *zamindar* to distinguish the soil conditions causing *tirak* the adoption of late sowing as a general measure is of great practical value.

Two schedules have been prepared for the guidance of the cultivators on the basis of experimental results. Schedule A gives an idea of the changing seed rate and spacing with advancing dates of sowing. Schedule B furnishes particulars as to the optimum sowing periods for the commonly-cultivated varieties in each district.

A large number of big as well as small cotton growers have recently based their practice on the above recommendations with encouraging results.

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ON PHOTOPERIODIC EFFECT OF JUTE PLANTS

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(With Plates IV and V)

The work of Garner and Allard [1920; 1923] and of Tincker [1925; 1928; 1929] showed that plants in their behaviour towards the length of light exposure, arrange themselves into three general groups according to the effect of the treatment upon the time of flowering: (*a*) those species and varieties which are apparently little affected in their time of flowering by the duration of the exposure to light—called '*neutral*' *plants* by some; (*b*) those plants which are caused to flower by the action of short days—called '*short day*' *plants*; and (*c*) those plants which are forced into flowering through the action of long days—called '*long day*' *plants*.

Lysenko showed that in the course of development the plant requires a different set of conditions for the different phases, an early one of which is the definite temperature requirement called the 'Vernalization stage' or 'Thermo stage'. This 'Thermo stage' is followed by a second stage in which the plant requires a certain length of day called 'Photo stage' (*Phasic development of plants*, 1935). Thus Lysenko's view of Photoperiodism is that the vernalization stage has to be followed by a 'Photo stage' for which a certain length of day is necessary. When this stage is completed the daily period of illumination no longer influences the time of flowering.

In India the influence of the length of the day on the course of development specially on the time of flowering has been recorded by Sen and Chakrabarty [1942] on mustard, Pal and Murthy [1941] on gram and wheat, Alam [1937] and Sircar [1942] on rice and Rhind [1935] on sesamum.

This paper contains the results of preliminary investigations on how far the length of the day is of influence on the growth and development of jute plants.

Experimental procedure

Corchorus Capsularis (D. 154) and *C. Olitorius* (Chinsura Green) the two recommended strains for the low and high lands respectively were used for the experiments. Seeds were obtained by the courtesy of the Director, Jute Agricultural Research Laboratories, Dacca.

On 20 April 1943 dry seeds were sown in earthenware pots 13 in.×13 in. containing well manured soil, at the rate of 40-50 seeds per pot at four different places equidistant from the centre and the wall of the pot. As the seedlings developed they were removed from time to time keeping four best plants in each pot, and were equally watered regularly except on rainy days. Experiments were devised in consultation with the Statistical Laboratory, Presidency College, Calcutta. For sufficient number of replicates 15 pots were taken for each species with 4 plants per pot, the pots being divided into three sets of 5 pots each, one set as control and the other two sets were exposed to two types of short day treatments. In the first treatment (Treatment I) the pots were removed to a specially constructed dark chamber in the field at about 4 p.m. and brought back outside at dusk from 25 April 1943, i.e. 5 days after sowing when the seedlings were distinct and exposed to this treatment for 60 days. In the second treatment (Treatment II) the exposure to similar treatment as above commenced after 30 days of growth in normal conditions and continued for 60 days as in the previous case. Thus the short day treatment meant an exposure shorter by 3 hr. approximately than the full day length which varied between 12 hr. 39 min. and 13 hr. 27 min. during the period. The treated plants were otherwise exposed to exactly the same conditions as the control.

To study the effect of treatments on the growth and development of the plants, the following measurements were recorded every week commencing from, when the plants were 30 days old till the maturity of the first fruit. Growth, however, continued slowly even after this.

(1) Height of the stem in cm.

(2) Number of nodes of the stem excluding undifferentiated nodes of the extreme apex.

(3) Number of leaves on the main stem. This included the newly unfolded immature leaves of the apical rosette.

(4) Number of leaves shed from the base of the stem. From these counts the life of the different leaves, the total number of leaves present on the main stem for active photosynthesis can be calculated.

In all the leaf counts the pairs of the cotyledonary leaves were taken as one leaf.

(5) Number of branches more than 5 cm. in length. They were counted under three heads, viz. (*a*) 5 cm. and more, (*b*) 15 cm. and more, and (*c*) 30 cm. and more.

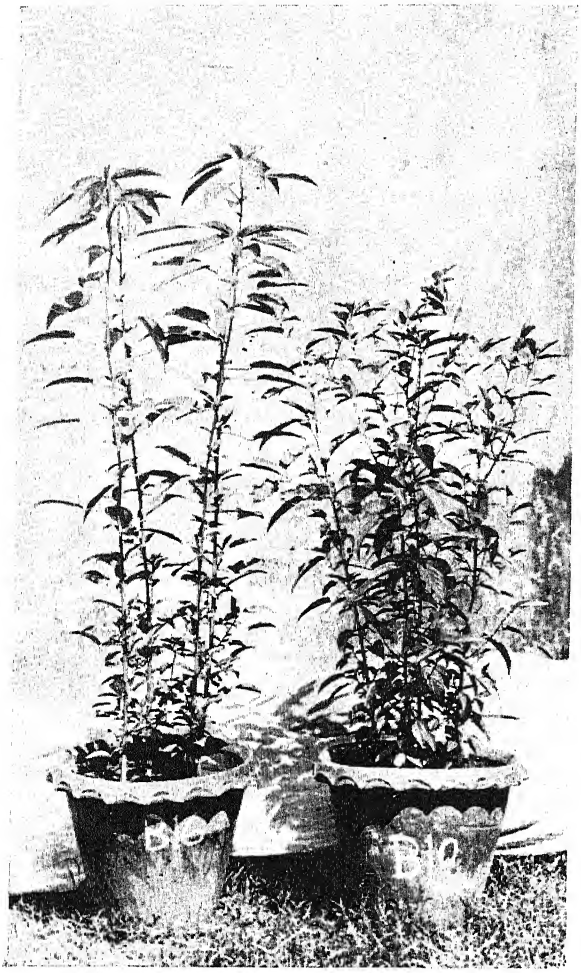
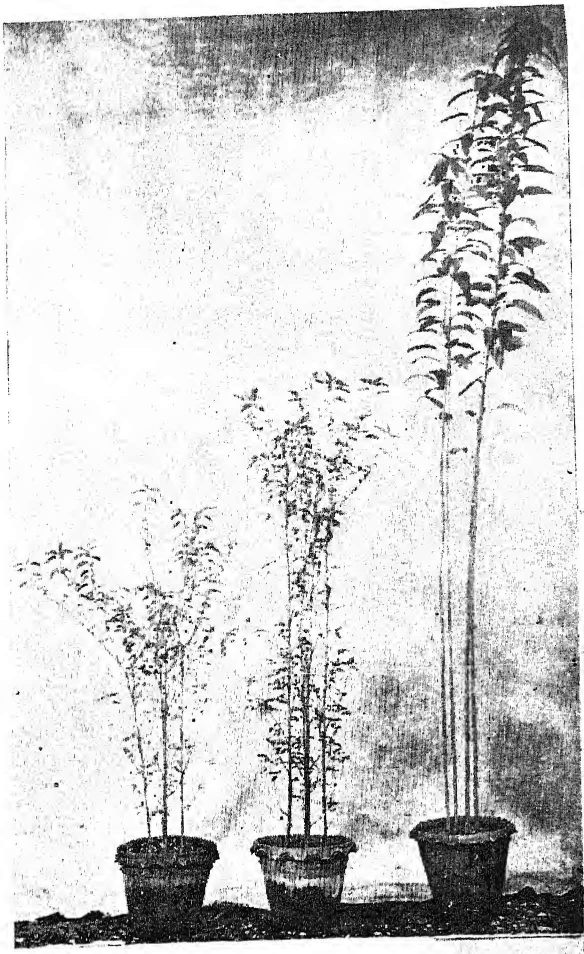


FIG. 1. Fifty-five days old *C. Capsularis* plants
(B16) Control—Vegetative ;
(B10) Treatment I—Fruiting

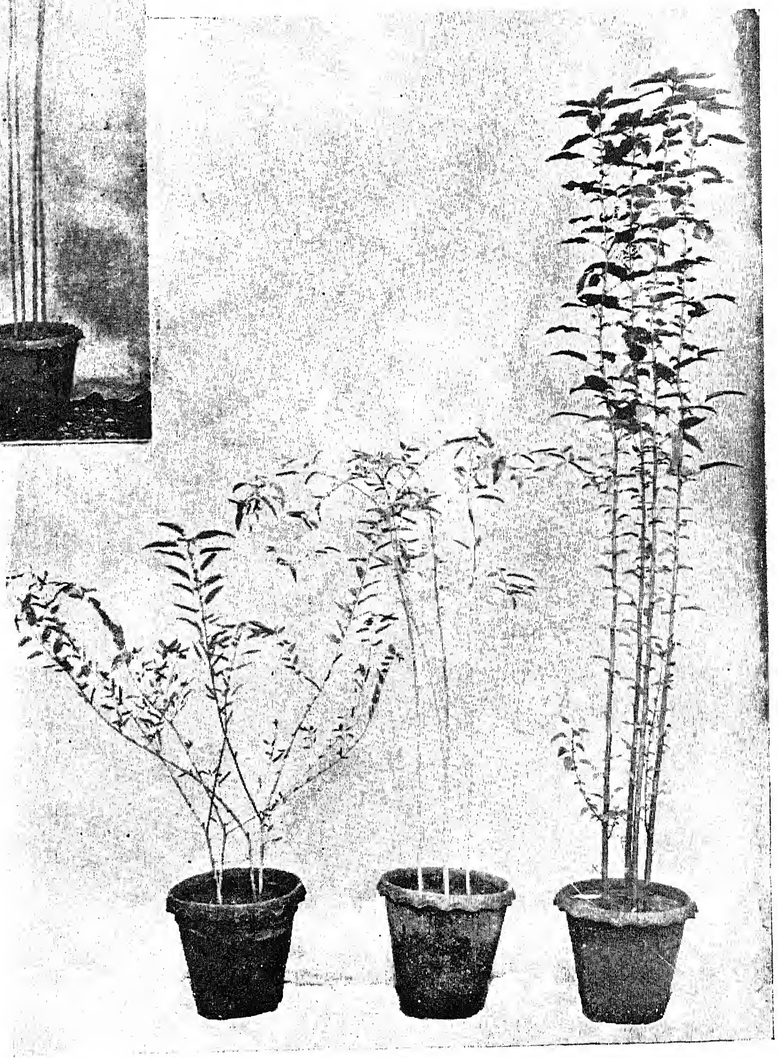
FIG. 2. Fifty-five days old *C. Olitorius* plants
(B32) Control—Vegetative ;
(B22) Treatment I—Fruiting

PLATE V



A B C

FIG. 1. 120 days old *C. Capsularis* plants (a) Treatment I with over-ripe fruits; (b) Treatment II with ripe fruits; (c) Control with flower buds



A B C

FIG. 2. 120 days old *C. Olitorius* plants (a) Treatment I with over-ripe fruits; (b) Treatment II with ripe fruits; (c) Control with flower buds

When the plants in a set began to flower, they were examined regularly and the time of the initiation of flower buds, fruits and maturity of fruits were noted for each plant. These data were recorded on the following basis :

(*a*) Differentiation of morphologically visible flower buds were taken as date of flowering.

(*b*) Differentiation of morphologically visible first fruit was taken as the date of fruiting, and

(*c*) Ripening of the first fruit was taken as the maturity of fruit.

In every case data were recorded for all the plants separately and the mean values are recorded in the different tables given below.

The mean time required for flowering and fruiting and the differences between the control and treated plants are given in Table I.

TABLE I

Time of flowering and fruiting

Treatment	Mean date of flowering in days	Earliness from control in days	Time of flowering in days after commencement of treatment	Mean date of fruiting in days	Earliness from control
	C. Capsularis				
Treatment I	32·6	81·5	27·6	47·6	87·0
Treatment II	47·4	66·7	17·4	60·4	74·2
Control	114·1			134·6	
	C. Olitorius				
Treatment I	27·8	98·1	22·8	36·0	99·4
Treatment II	44·4	81·5	14·4	56·3	79·1
Control	125·9			135·4	

It is seen that the plants exposed to short days flowered and fruited much earlier than the control and of the two treatments, plants of Treatment I flowered and fruited earlier than those of Treatment II. Plants of Treatment II responded much earlier after commencement of treatment than those of Treatment I.

It is found that a great development of a branch from an axiliary bud near the apex of the stem leading to the look of an apical split is associated with the initiation and production of flower buds, flowers and fruits.

Mean heights of plants in different treatments are given in Table II.

It is found that the treated plants which are seen to flower much earlier (Table I) also remained short. Thus earliness of flowering due to short day treatment is associated with checked growth (vegetative) in length. It is seen that of the two treatments plants of Treatment I remained shorter than those of Treatment II.

It is found that the apical branch grows longer and longer almost equally as the main stem at the apical portion, which now grows in an inclined manner (pronounced in *C. Olitorius* and less in *C. Capsularis*), and thus these two subtend an angle at the apex giving the appearance more or less of a Y type, the angle being more or less 90° in *C. Capsularis* and about 145° in *C. Olitorius*.

The mean number of total nodes at different stages are given in Table III.

It is seen that the number of nodes is much greater in the control than in the treated ones and between the two treatments, plants of Treatment II had a larger number of internodes than those of Treatment I.

The number of branches separately under 5 cm. and more, 15 cm. and more and 30 cm. and more are recorded in Tables IV and IV-A.

It is seen that the treated plants developed a greater number of branches than the control under all the three heads in *C. Capsularis,* where the difference between the two treatments is that the total number of branches 5 cm. and more is greater in Treatment II, whereas those of 15 cm. and more are distinctly greater and of 30 cm. and more slightly greater in Treatment I.

Thus *C. Capsularis* of Treatment I developed a larger number of branches and became more bushy than those of Treatment II which developed a larger number of shorter branches.

In *C. Olitorius* branches began to be produced first in Treatment I, then in Treatment II, much earlier than the Control. These branches slowly increased in length and at the time of maturity of fruit, the plants of Treatment I (65 days after sowing) had the largest number of branches. In the long run, however, control plants produced the largest number of branches of both 5 cm.-15 cm. or 15 cm.-30 cm., but there was no appreciable difference with branches more than 30 cm. Plants of Treatment II produced lesser number of smaller branches.

The total number of leaves on the main stem and those dead from base as the plant grew are recorded in Tables V and VI.

Table II

Height in cm.

	Days after sowing																
	30	37	44	51	58	65	72	79	86	93	100	107	114	121	128	135	142
	C. Capsularis																
Treatment I .	35·81	63·50	83·57	97·79	105·86	108·20											
Treatment II .		72·39	99·06	119·13	138·68	153·67	156·21	157·48	150·48	157·99							
Control . .	44·96	73·41	100·58	122·68	140·46	157·48	169·16	183·89		209·04	223·52	238·76		260·86	269·24	284·48	
	C. Olitorius																
Treatment I .	18·54	39·62	54·88	69·31	78·99	85·60											
Treatment II .		48.26	72·90	95·00	117·86	128·27	132·08	135·64	140·22								
Control . .	30·23	54·10	82·04	108·46	132·33	160·02	184·30	201·93		241·05	252·98	270·51		286·42	318·52	327·66	

Table III

Number of nodes

	Days after sowing																
	30	37	44	51	58	65	72	79	86	93	100	107	114	121	128	135	142
	C. Capsularis																
Treatment I .	12·2	19·9	23·3	28·1	29·6	30·0											
Treatment II .		18·5	25·4	36·2	39·5	42·6	43·7	44·7	46·5	47·2							
Control . .	12·2	18·5	23·2	31·3	35·2	40·8	45·0	51·8	...	58·3	64·1	69·1	...	77·8	79·2	82·4	85·4
	C. Olitorius																
Treatment I .	8·4	12·2	16·0	23·4	26·3	28·5											
Treatment II .		13·5	20·5	33·5	37·6	39·5	41·3	43·3	44·7								
Control . .	9·8	14·8	22·9	30·0	37·7	44·1	48·4	58·1	...	67·9	72·9	78·6	...	84·3	95·3	101·3	106·3

TABLE IV

Number of branches

(*C. Capsularis*)

	Days after sowing																
	30	37	44	51	58	65	72	79	86	93	100	107	114	121	128	135	142
CONTROL																	
Branches 5 cm. or more		0·7	2·6	1·6	1·9	2·5	2·5	2·2	...	2·1	1·8	2·0	...	2·2	3·6	5·2	7·5
Branches 15 cm. or more			0·35	0·80	0·78	0·89	0·74	0·82	...	0·83	0·83	0·88	...	0·86	1·7	3·2	5·0
Branches 30 cm. or more			0·15	0·25	0·25	0·25	0·25	0·36	...	0·30	0·50	0·55	...	0·32	0·53	1·0	2·4
TREATMENT I																	
Branches 5 cm. or more		*	13·4	14·1	14·4	14·3											
Branches 15 cm. or more			1·4	8·9	8·9	9·8											
Branches 30 cm. or more				2·4	2·7	2·9											
TREATMENT II																	
Branches 5 cm. or more		0·6	1·9	2·1	7·4	15·2	13·6	16·4	19·3	19·5							
Branches 15 cm. or more			0·5	0·9	2·2	3·9	3·7	4·8	6·0	6·5							
Branches 30 cm. or more			0·2	0·3	0·5	0·9	1·9	2·3	2·4	2·5							

* Total No. of branches was not recorded

Table IV-A

Number of branches

(C. Olitorius)

	Days after sowing																
	30	37	44	51	58	65	72	79	86	93	100	107	114	121	128	135	142
CONTROL																	
Branches 5 cm. or more						0·1	0·6	0·9	...	1·6	1·7	2·9	...	6·9	7·1	10·0	13·0
Branches 15 cm. or more							0·1	0·3	...	0·5	0·4	0·4	...	0·93	1·6	2·8	5·0
Branches 30 cm. or more														0·1	0·3	0·7	1·7
TREATMENT I																	
Branches 5 cm. or more		*	3·9	3·0	5·2	5·0											
Branches 15 cm. or more			0·9	2·1	2·1	2·5											
Branches 30 cm. or more				1·0	1·1	1·4											
TREATMEET II																	
Branches 5 cm. or more				1·8	3·5	3·5	3·2	3·4	3·5								
Branches 15 cm. or more				0·7	2·0	2·4	2·6	2·7	2·8								
Branches 30 cm. or more					1·8	1·9	1·8	1·8	1·8								

* Total No. of branches was not recorded

TABLE V

Total leaves produced on the main stem

	Days after sowing																
	30	37	44	51	58	65	72	79	86	93	100	107	114	121	128	136	142
C. Capsularis																	
Treatment I .	16·2	20·2	23·0	28·7	30·4	31·0											
Treatment II .		20·7	29·7	37·7	40·3	43·0	44·3	44·7	45·3	45·4							
Control . .	16·5	21·2	27·7	35·3	40·6	45·5	49·8	55·4	...	64·3	69·1	74·0	...	80·05	81·1	83·8	87·0
C. Olitorius																	
Treatment I .	12·4	13·0	20·2	25·1	27·8	29·4											
Treatment II .		16·9	24·6	34·2	37·9	40·0	42·0	44·6	47·1								
Control . .	14·0	19·1	24·1	35·1	42·7	49·2	52·8	59·5	...	71·8	78·0	83·3	...	94·8	98·3	103·4	108·3

TABLE VI

Total leaves dead from base

	Days after sowing																
	30	37	44	51	58	65	72	79	86	93	100	107	114	121	128	136	142
C. Capsularis																	
Treatment I .	1·3	1·3	2·2	9·0	13·9	19·0											
Treatment II .		1·1	2·2	6·0	7·8	17·4	23·8	28·4	38·3	41·7							
Control . .	1·1	1·3	2·2	4·4	6·7	9·1	11·1	14·8	20·6	23·8	27·2	...	...	43·9	51·6	56·7	63·1
C. Olitorius																	
Treatment I .		0·7	1·2	7·0	8·7	12·0											
Treatment II .		0·7	1·6	8·7	10·4	15·5	18·7	23·3	32·7								
Control . .	0·2	1·4	2·1	7·4	11·5	15·6	18·4	21·3	...	32·1	39·6	...	...	59·1	60·6	68·8	78·3

It is seen that the total number of leaves is much greater in the control than in the treated ones and there were more leaves developed on the plants of Treatment II than those of Treatment I.

Regarding the shedding of leaves, it is found that in *C. Capsularis* plants of Treatment II shed the largest number, second came the controls and last those of Treatment I, and in *C. Olitorius* the controls shed the most, next came plants of Treatment II and last those of Treatment I.

It should however be remembered that the total height, and number of internodes were much greater in the controls.

By following the course of developmental changes studied under different heads by weekly measurements it is seen that the stages at which the well marked differences between the controls and treated ones mentioned above began to be evident are as follows: (*a*) Height—from the time of the initiation of fruits, (*b*) Nodes—from the time of the initiation of fruits, (*c*) Branching—rapid development after flowering, (*d*) Leaf—from the initiation of fruits, and (*e*) shedding of leaves—after setting of fruits. Thus the modifications undergone by the plants under short day treatments are associated with the onset of flowering and fruiting.

Discussion

From the results of the experiments both the species of Jute seems to come under *'short day' plants*. The plants show a remarkable earliness of flowering associated with a remarkable modification of the vegetative growth under short day treatments as a result of which the plants remain shorter and become bushy. But from the experiment and results nothing can be said about the critical light period, critical duration of exposure to short day treatment and whether there is Photoperiodic Induction in the plant. It is, however, clearly seen that in the *'short day'* treated plants the sexual phase which sets in earlier continues vigorously in the production of flowers and fruits at the cost of vegetative growth which is considerably checked.

Regarding the significance of the photoperiodic effect mentioned for economic utility, earliness of flowering and checked vegetative growth will be of no use so far as the yield of fibre is concerned. But it can be useful for breeding experiments where it will be possible to study more than one generation during one season, and to seed farms for raising more than one generation in one season. The results also show a possibility of the vegetative stage being lengthened by long day treatments in which case it becomes of utility even in connection with fibre production of the plant.

Summary

1. Two species of jute plants *C. Capsularis* (D154) and *C. Olitorius* (Chinsura Green) were grown in pots and exposed to a daily light period shortened by 3 hr. at two stages, (*i*) from the beginning, after germination, and (*ii*) when the plants were 30 days old, till flowering and fruiting.

2. Both the species responded to treatment by early flowering and fruiting over the control, treatment from the beginning being more effective.

3. Early induction of sexual phase greatly modified the course of vegetative development and response in this respect being more pronounced in the first treatment.

4. Response to short-day treatments resulted in a lower height, lower number of nodes, lower number of leaves, greater number of branches, smaller diameter of the stem and thus in shorter and bushy plants.

5. The response in vegetative development like height, number of nodes, leaves, and branches began to be evident from the time of flowering and fruiting.

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STUDIES ON BASE EXCHANGE

II. A COMPARISON OF DIFFERENT METHODS OF ESTIMATING BASE-EXCHANGE CAPACITIES AND OF LIME REQUIREMENT OF HYDROGEN CLAYS, ACID SOILS* AND PARTLY AND COMPLETELY DESATURATED SOILS†

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(With two text-figures)

THE variations in the total acid of hydrogen clays estimated by different methods are controlled by the *p*H and two types of cation effects [Mukherjee, Mitra and Mukherjee, 1937; Mitra, Mukherjee and Bagchi, 1940; Mitra and Mitra, 1940; Mukherjee, Mitra, Mukherjee and Chatterjee, 1942; Mukherjee and Mitra, 1942]. The *p*H effect is generally recognized but its nature is not clearly defined. It is illustrated by the continued buffering in the reaction between hydrogen clays and alkalis showing that more and more acid is neutralized by the base as the *p*H rises. The cation effect is illustrated by the following results: The b. e. c. calculated from the titration curves with different bases at a fixed *p*H, e.g. 7·0, decreases in the order $Ca(OH)_2 > Ba(OH)_2 > NaOH$. The effects of the various cations are in the order $Ca^{++} > Ba^{++} > Na^{+}$. This is in violation of the usual lyotrope series and has been termed the 'Irregular' or 'Specific cation effect'. When a neutral salt is added to a hydrogen clay a considerable amount of titratable acid is found in the supernatant liquid. Using a fixed concentration of different salts having a common anion which does not enter into chemical reaction with the hydrogen clay the total acid of the supernatant liquid has been found to decrease in the order $Ba^{++} > Ca^{++} > Na^{+}$. This order illustrates what has been termed the 'Regular cation effect' in the sense that the relative effects of the cations are in agreement with the lyotrope series. It is, however, to be noted that in the case of cations like Ca^{++} or Ba^{++} which do not differ much in their exchange properties, the difference between the amounts of these cations reacting with the hydrogen clay is not so marked as it is between widely differing cations like Ca^{++} or Ba^{++} and Na^{+}, especially when the other factors, viz. concentration and *p*H, are high.

In the light of the work cited above it appears that when the salt concentration is high, the *p*H sufficiently high and the adsorption of cations strong, differences in the nature of the cation or *p*H should not much affect the estimated values of the base exchange capacity and those routine methods which satisfy more or less these conditions show fair agreement amongst themselves. But the differences as they exist are worthy of close scrutiny and it is also desirable to ascertain by varying the above factors whether there is a maximum limiting quantity of reacting acid associated with a given mass of a hydrogen clay or soil§. A comparative study has, therefore, been made of several routine methods for determining the b. e. c. of hydrogen clays and acid soils||.

The hydrogen clays were prepared according to the procedure described in the earlier publications.

Lab.	*Description of soil*	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
51	Highland acid soil on old alluvium from Jorhat, Assam; unmanured, uncultivated, virgin soil under thatch grass	2·58	2·80
53	Highland acid soil on old alluvium from Latekujan, Assam; unmanured, uncultivated virgin soil representing the submontane tract .	2·47	2·70

A comparison has been made of the following methods:

1. Parker's [1929] method—Ba^{++} adsorbed from a neutral, normal barium acetate solution was estimated.

* The expression 'acid soil' has been used to denote, as is usual, natural soils with an acid reaction and 'hydrogen soils' to denote desaturated soils obtained by exhaustive leaching with 0·02 N HCl assuming that the desaturation has been complete

† The results given in this paper were published in the Annual Report for 1939-40 on the working of the scheme of research into the properties of colloid soil constituents financed by the Imperial Council of Agricultural Research and directed by Prof. J. N. Mukherjee

** Assistant Soil Chemist under the above scheme during 1938-39

§ Some results on the attainment of a limiting value of the b. e. c. of soils have been already published in the *Proc. Indian Sci. Cong. Association* 1941. Results of further investigation will shortly be published

|| A similar comparative study was carried out by Mitra and Mitra in this laboratory (*Indian J. agric. Sci.* **10**, 344)

2. Schollenberger's [1930] method—NH_4+ adsorbed from a neutral normal solution of ammonium acetate was estimated.

3. Schofield's [1933] method—The amount of base taken up from a half neutralized (with lime) p-nitrophenol was estimated. The reaction takes place at pH 7·1.

4. Estimation of the amount of baryta taken up in presence of normal barium chloride to attain pH 7·0. This was determined as follows: To equal amounts (0·5 to 1·0 gm.) of the hydrogen clay to which equal volumes of N-$BaCl_2$ had been added in well-stoppered Jena bottles, increasing quantities of baryta were added. The mixtures were kept overnight with occasional shaking and their pH values measured by means of the glass electrode. From the titration curve thus obtained, the amount of base required to reach pH 7·0 was calculated.

5. Continuous potentiometric titration of the hydrogen clay (25 c.c. of a suspension of 10-20 gm./litre) with baryta in presence of N-$BaCl_2$ was carried out with the help of the glass electrode and the total acidity calculated from the amount of base taken up to reach pH 7·0. The time of interaction does not usually exceed 6 hours in these titrations.

6. The amounts of cation adsorbed on leaching with neutral normal solutions of NH_4Cl, $BaCl_2$ and $CaCl_2$ were also estimated. 500 c.c. of salt solution were used to leach the hydrogen clays (0·5 to 1·09). The quantities of Ba^{++} and Ca^{++} adsorbed were estimated in the leachate obtained with N-NH_4Cl. NH_4^+ adsorbed by the residue after it has been washed free of chloride was estimated by distilling with magnesia.

The results are given in Table I.

TABLE I

Hydrogen clay	N-$BaCl_2$—$Ba(OH)_2$ continuous titration (*i*)	N-$BaCl_2$-$Ba(OH)_2$ bottle titration (*ii*)	Parker (*iii*)	Schollenberger (*iv*)	Schofield (*v*)	Cation adsorbed		
						NH_4^+	Ba^{++}	Ca^{++}
Jorhat-F (from soil No. 51)	29·5	33·0	33·0	32·0	35·0	34·0	22·0	20·5
Latekujan-F (from soil No. 53)	51·5	56·5	54·0	55·0	55·0	56·0	42·0	40·0

Methods 1 and 2 give nearly the same values.* The close agreement between these two methods has been observed in the case of soils also in Part I of this paper. Method 3 gives a somewhat higher value with the hydrogen clay, Jorhat-F. Total neutralizable acidity calculated from the amonnt of base required to attain pH 7·0 (curves 1 and 2 for hydrogen clays JF and LF respectively, Fig. 1) is lower than those obtained by the other methods. If a longer time of interaction is allowed the titration with baryta in presence of N-$BaCl_2$ (curves 1′ and 2′ for hydrogen clays JF and LF, respectively, Fig. 1) gives values in general agreement with the above methods. Similar agreement was obtained in the case of hydrogen soils. Time of interaction is therefore one of the important factors in the reaction between the hydrogen clay and base.

In method 3 [Schofield, 1933] the cation (calcium) concentration is low (about N/50); in spite of this it gives values in close agreement with or even higher than the values obtained by the methods 1 and 2. This method has the distinction that it ensures a maximum buffering. The p-nitrophenol-hydrogen clay mixture is maintained throughout at pH 7·1. In the other methods, at least the initial stages of the interaction with base occur at a lower pH. The adsorption of Ca^{++} is quite strong in alkaline or neutral region [Mukherjee, Mitra and Mukherjee, 1937; Mitra, Mukherjee and Bagchi, 1940; Mitra, 1940; Mukherjee and Mitra, 1942]. The method also allows a long interval (16 to 18 hours) for the interaction. In the methods 1 and 2 it has been observed that on the addition of the hydrogen soil the neutral reaction of the salt solution is perceptibly displaced to the acid side of the pH scale. Similar lowering occurs with hydrogen clays and hence maximum buffering is not obtained.

The last three columns of Table I indicate that the order of adsorption of the cation from their neutral normal solutions is $NH_4^+ > Ba^{++} > Ca^{++}$. NH_4^+ adsorbed is almost equal to the maximum b. e. c. of the hydrogen clays given by the other methods. Similar observations have been made

* The features of the titration curves given in Fig. 1 are not discussed here; this will be done in another publication

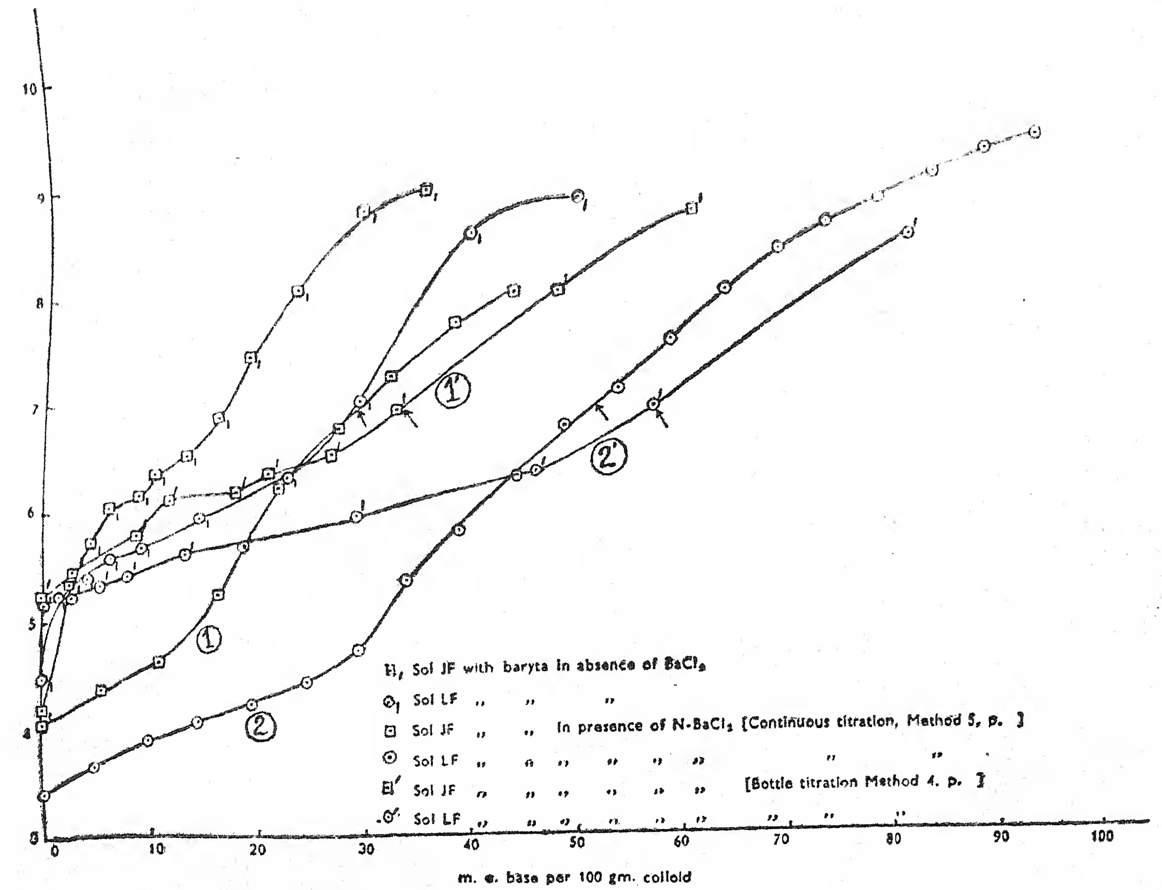

FIG. 1

with hydrogen soils (described below). The greater adsorption of NH_4^+ compared to either Ba^{++} or Ca^{++} ions is interesting.

Considering the electrical double layer [Mukherjee, 1922] associated with a hydrogen clay particle the reaction with a neutral salt can be visualized as follows: When a fairly high concentration of a salt is added to the hydrogen clay its cations will displace both free and bound hydrogen ions from the complex. The extent to which this exchange and desorption of hydrogen ions take place is indicated by the equilibrium pH of the mixture and will depend on the nature of the added cation. At all pH lower than the equilibrium pH the hydrogen ions will tend to be adsorbed at the expense of the added cation. At the high concentration (normal) of the salts usually employed for leaching the difference in the cation effects is not very large and it appears that the greater adsorption of NH_4 ion mainly results from the higher equilibrium pH of the mixture of hydrogen clay and NH_4Cl. In other words, under these conditions the pH effect becomes dominant. In the methods of Parker and Schollenberger the acetates act as buffer solutions so that leaching proceeds at a pH not far removed from 7·0.

The effects of the pH of the leaching solutions on cation adsorption and its relative order have been examined with respect to three 'hydrogen' soils prepared from the following soils by exhaustive leaching with 0·05N HCl. They were then washed free from HCl and air dried.

Lab. No.	*Description*
20	Kalyanpur Agricultural Farm soil, collected from a depth of 0-6 in. A typical loam
16A	Krishnagar Farm soil, collected from a depth of 6-12 in. A highland soil from Nadia
56	Oating Farm soil from Assam, collected from a depth of 6-12 in., from the fringe of the Mikir Hills, Assam. A highland acid soil, uncultivated and unmanured

The leaching and estimation of the cations adsorbed thereby were done by the procedure described earlier. The residual soil after treatment with N-NH_4Cl used for replacing the adsorbed cation was washed with alcohol until free from electrolytes. The adsorbed NH_4^+ was then

estimated by distillation with magnesia. The values are shown in the last two columns of Table II. The pH values of the leachates are generally less than those of the corresponding leaching solutions but the difference is almost negligible with NH_4Cl. When leaching has proceeded for a long time an almost constant pH is attained which is shown as the 'limiting' pH in Table II. One salt only was used for determining the 'limiting' pH for a particular soil. Neutral N-$BaCl_2$ for soil No. 20, neutral N-$CaCl_2$ for soil No. 16A and neutral N-NH_4Cl for soil No. 56 were used.

TABLE II

	Initial pH of salt solution	Limiting pH	pH of residual soil	pH of original soil	Amounts of cation adsorbed			NH_4+ adsorbed from NH_4Cl to displace adsorbed	
					Ba++	Ca++	NH_4+	Ba++	Ca++
Kalyanpur H-soil b. e. c. 11·9	2·2	2·3	4·2	..	3·7	3·2	5·8	10·4	10·2
	4·6	4·5	5·2	4·3	6·5	6·8	11·3	11·5	11·6
	7·0	6·0	5·5	..	7·1	8·1	11·7	11·6	11·6
	8·5	6·4	6·0	..	7·4	8·7	12·7	11·7	12·5
Krishnagar H-soil b. e. c. 9·2	2·0	2·1	4·2	..	2·9	2·4	4·8	9·0	9·0
	4·0	4·1	5·0	3·8	6·1	5·5	7·2	9·1	9·2
	7·0	5·9	5·8	..	6·3	6·4	9·0	..	..
	8·5	6·3	6·2	..	6·8	7·2	9·4	9·5	9·5
Oating H-soil b. e. c. 6·2	3·2	3·2	4·8	..	3·1	2·9	4·3	6·3	6·2
	7·0	6·8	7·8	3·5	3·2	3·4	6·3	6·4	..
	8·7	8·3	8·2	..	3·2	3·7	6·8	6·4	..

The limiting pH of NH_4Cl leachings is nearly the same as that of the stock solution used whereas those of the leachates of $BaCl_2$ and $CaCl_2$ are lower than those of the respective stock solutions.

The pH values of the treated soils on removal of the salt by washing after the leaching (the residual soil) are also recorded in Table II. They show that the residual soils have a more or less acidic reaction even when the leaching solutions were neutral $BaCl_2$ and $CaCl_2$. The acidic reaction definitely indicates the presence of unexchanged and osmotically active hydrogen ions in the complex.

The amounts of cation adsorbed have been plotted (Fig. 2) against the limiting pH*. Ba++ and Ca++ show reversal of the order of adsorption at pH between 4·0 and 6·0†. The Kalyanpore hydrogen soil shows it at 4·2, the Krishnagar hydrogen soil at 5·6. The adsorption of NH_4^+ ion follows a different but an apparently regular course.

ESTIMATION OF THE LIME REQUIREMENT OF ACID, PARTLY DESATURATED AND HYDROGEN SOILS BY DIFFERENT METHODS

The methods of estimating the lime requirement of acid soils aim at measuring the content of exchangeable hydrogen. The large number of methods available for this purpose seldom give concordant values. The two types of cation effects the hydrogen ion activity of the solution and the time of interaction, as already mentioned and discussed in the preceding pages appear to afford a consistent explanation of the observed variations in these estimations.

The following methods have been used for comparison :

(3) Schofield's method [1933]

(4) Bottle titration

(7) Kappen's method [1916]

* In plotting these curves it has been assumed that the limiting pH values with $BaCl_2$ and $CaCl_2$ solutions are the same with all the soils, and those of NH_4Cl leachates the same as those of the salt solutions themselves. This can only be treated as a very rough approximation.

† Results on the interaction between hydrogen clays and baryta and lime obtained in this laboratory also show a similar reversal of adsorption of Ba++ and Ca++ ions.

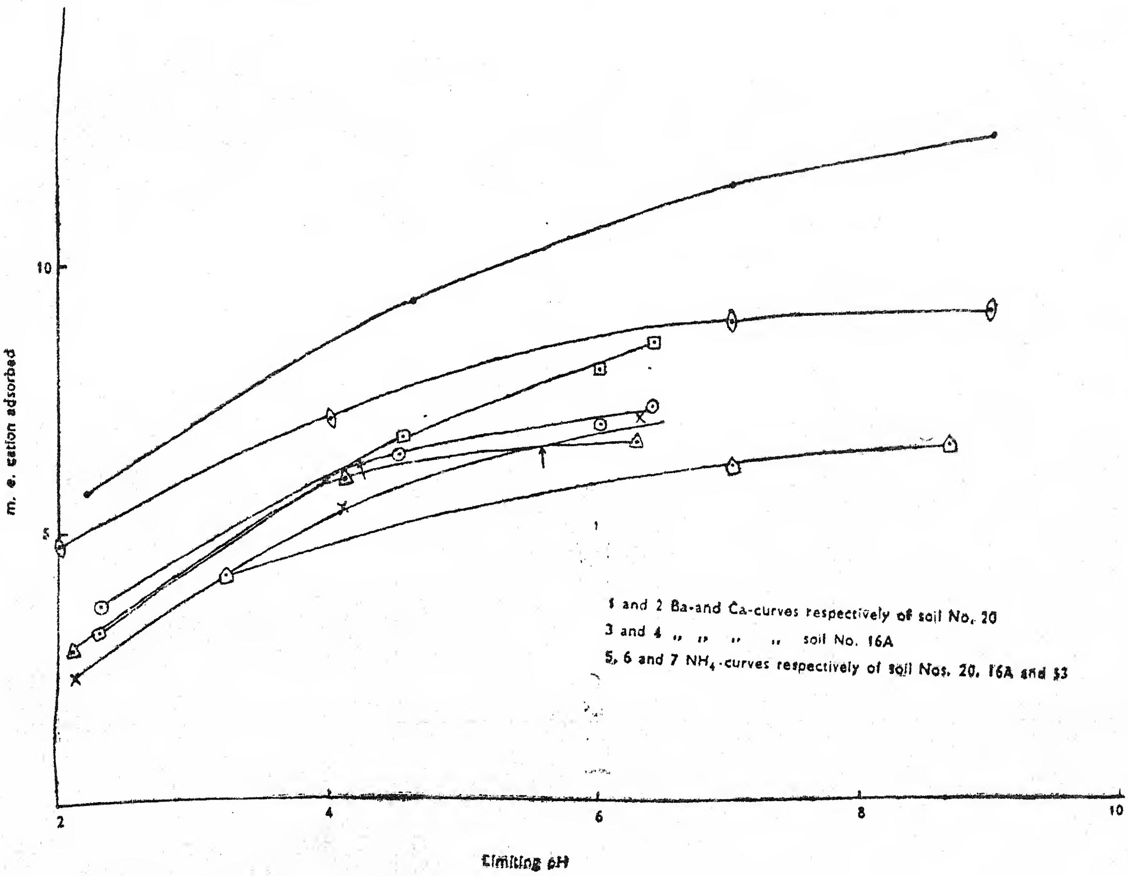

FIG. 2

(8) Daikuhara's method [1914]

(9) Parker's $Ba(OH)_2$—NH_4Cl method [1929]

(10) Hutchinson and McLennan's method [1914]

The two 'acid' soils (Nos. 51 and 53) and the following soils which were only partially desaturated have been used for the estimation of lime requirement.

Lab. No.	*Description*
16A	Krishnagar farm soil, Highland soil (0-6 in.).
34	Black cotton soil from Akola, C. P. (0-6 in.).

The two acid soils Nos. 51 and 53 were also completely desaturated and in addition the resulting hydrogen soils have been used making a total of six samples for this comparison.

Table III gives a comparative study of the values of b. e. c. of three naturally occurring soils used in this investigation and the H-soils§ prepared from them. The b. e. c. has been determined using either method 1 or 2 or both. The agreement between the b. e. c. of the naturally occurring soil and the corresponding H-soil shows that the base exchange property of the soil remains unaltered when converted to the H-soil. Methods of determining lime requirement of soils may therefore be applied to H-soils and the values so obtained may be compared with the b. e. c. of the soils themselves.

Table IV shows the results of the lime requirment of a number of acid and H-soils by the various routine methods. The b. e. c. (T) and the amount of exchangeable bases (S) were estimated by method 2. The quantity T—S in column 4 (Table IV) should be equal to the estimated lime requirement. This quantity is, however, obtained by computation as a difference between two quan_

§ Soil No. 16A was also partly desaturated

TABLE III

Soil No.	Naturally occurring soil		Partly desaturated		H-soil	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
16A . . .	..	9·0	..	8·5	9·2	9·2
20 . . .	11·6 11·8	11·9	..	..	..	11·9
53 . . .	8·0 8·3	8·2 7·5	..	..	..	7·5

tities and is liable to a greater error than the quantities T and S and the error will be greater the smaller is the difference compared to the values of T and S. The S-value should not vary provided all the exchangeable bases have been displaced and estimated; but as we have seen the T-value depends on the method employed for its determination.

TABLE IV

Soil No.	T*	S*	T-S	Lime requirement by methods†					
				7	8	4	9	3	10
16A (Partly desaturated) .	8·5	1·8	6·7	5·3	6·0	..	..	..	..
34 (Partly desaturated) .	54·7	20·5	34·2	14·2	14·0	..	..	..	..
51	5·9	1·9	4·0	4·0	1·8	5·8	..	5·6	4·5
51 (H-Soil)	5·9	..	5·9	6·0	5·8	6·8	7·2	7·5	5·9
53	7·5	3·3	4·2	3·9	4·1	5·4	..	5·9	4·5
53 (H-Soil)	7·5	..	7·5	6·5	6·9	7·6	8·4	8·0	7·7

* Estimated by Schollenberger's method

† Expressed in m. e. per 100 gm. of hydrogen soil

Methods 7 and 8§ give values in agreement with T—S in the case of the two acid soils where the amount of exchangeable hydrogen was small but they give smaller values for Nos. 16A and 34, especially the latter which contain larger amounts of exchangeable hydrogen. This observation can be understood from the balanced nature of the reaction between the acid soil and the salt solutions. In the case where the content of exchangeable hydrogen is large the *p*H of the medium appreciably diminishes and the back reaction is favoured but in the case where the amount of exchangeable hydrogen is small the *p*H of the solution does not change to any appreciable extent.

The single treatment used in the methods 7 and 8 seems to be sufficient for soils having comparatively small lime requirement. The agreement between methods 7 and 8, although they involve different cation effects, probably arises from the fact that the latter uses an empirical factor (3·5) by which the titre value of the first leachate is to be multiplied.

Methods 3, 4 and 9 give higher values than T—S given in column 4. In method 4 a longer time of interaction is allowed, in 9 the soil is kept in contact with a 0·1 N $Ba(OH)_2$ solution for about 18 hours, and in 3 the soil is kept in contact with a solution of *p*H 7·1 for about 16 hours. The three methods (3, 4 and 9) ensure that *p*H, the concentration of a strongly adsorbed cation and the time of interaction are all fairly high. The differences shown between them indicate the extent to which one or more of the factors are dominant. They give a higher estimation of the exchangeable

§ A much smaller value is obtained for soil No. 51

hydrogen than obtained by methods 1 and 2. In method 10 the cation (Ca^{++}) concentration is about N/50, the pH of the bicarbonate solution is 6·6 which rises to 7·1 on treatment with the soil but the shorter time of interaction (3 hours) probably explains the low values obtained by this method compared to the above three. The latter values are however in good agreement with the T—S. Probably the methods 3, 4 and 9 estimate less reactive hydrogen ions in addition to the more reactive ones estimated by the method 10 or included in the quantity T—S.

Summary and conclusion

1. In view of the lack of agreement amongst the various methods of determining the base exchange capacity (b. e. c.) of soil, a comparative study has been made of several routine methods using hydrogen clays and hydrogen and acid soils. It would appear from the results recorded in this paper that the differences in the cation and pH effects and the time of interaction account for this lack of agreement.

2. It has been found that Parker's and Schollenberger's methods give nearly the same value. At the high pH, high concentration of the salts and at the neutral reaction the cation effect practically vanishes. Schofield's method gives a somewhat higher value. This may be accounted for (1) by the neutral reaction (pH 7·1), (2) by the greater adsorption of Ca^{++} in this pH region and (3) longer time of interaction (16 to 18 hours). The continuous titration (which takes about 6 hours) of hydrogen clays with baryta in presence of normal barium chloride gives a lower values but if the titration is carried out in bottles allowing a longer time of reaction (about 16 hours), the observed b. e. c. is in good agreement with either Parker's or Schollenberger's method.

3. The amounts of Ba, Ca and NH_4 adsorbed by the hydrogen clay from neutral normal solution of their chlorides are in the order $NH_4^+ > Ba^{++} > Ca^{++}$.

4. It has been observed that the pH of the successive leachates with $BaCl_2$, $CaCl_2$ and NH_4Cl gradually increases reaching a constant value. This 'limiting' pH in the case of NH_4Cl is higher than those in the case of $BaCl_2$ and $CaCl_2$. pH effect is the dominant factor in determining the greater adsorption of NH_4^+.

5. The adsorption of Ba^{++}, Ca^{++} and NH_4^+ from their chloride solutions increases with the pH of the leaching solutions. The adsorption of Ca^{++} and Ba^{++} shows reversal between pH 4 and 6.

6. The base exchange property of a soil remains in tact when it is converted into the H-soil. Methods of determining lime requirement may therefore be applied to soils after converting them to H-soils and the values of lime requirement may be compared with their b.e.c. Lime requirements of some acid, partly desaturated and hydrogen soils were determined by six different methods. The values obtained by the various methods were compared with T-S obtained by Schollenberger's method. The methods of Kappen and Daikuhara are in good agreement with that of Schollenberger when the amount of exchangeable hydrogen is small but they give smaller values for soils which contain larger amount of exchangeable hydrogen. Titration with baryta in presence of N-$BaCl_2$ using longer time of interaction (bottle titration) gives higher values than by continuous titration. Parker's $Ba(OH)_2$-NH_4Cl and Schofield's methods give values higher than T-S. The higher values are to be ascribed to the pH and time effects only. The lower value obtained by Hutchinson and McLennan's method in which the pH is also 7·1 is due to the shorter period of interaction (3 hours).

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STUDIES IN SOIL DISPERSION

II. EFFECT OF *p*H VALUE AND THE NATURE OF EXCHANGEABLE BASE ON DISPERSION OF SOIL

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IT has been shown that dispersion is complete and at its maximum when the *p*H value of a H-soil is made equal to 10·8 by the addition of NaOH or LiOH [Puri and Manohar Lal, 1938]. Some interesting considerations arise out of this, namely, whether the soil, at different *p*H values, which is not at its maximum dispersion, represents a stable structure or it is merely a question of time. It is quite likely that the rate of dispersion of soil at different *p*H values might be different, in which case it would be more helpful to measure the rate of dispersion. The development of the Chaino-hydrometer [Puri and Puri, 1939] for the mechanical analysis of soils has made this study possible because the same suspension could be examined at different intervals of time which would not have been possible with the pipette method.

RATE OF DISPERSION OF SODIUM-SOIL

A black cotton soil (lab. No. P. C. 13) was freed from exchangeable bases by treatment with *0·05 N*HCl. Increasing amounts of NaOH were then added to the treated soil and the volume made to give a 2 per cent suspension. Particles of 0·005 mm. were determined at various intervals of time. The results are given in Table I. The readings were continued for 50 days after which the suspensions were heated for 10 hours at 60-70°C. It will be seen from Table I that differences due to *p*H values are maintained throughout. There is, however, a slight tendency for the dispersion to increase during 5-7 days up to *p*H 10 or so. Dispersions at higher *p*H values seem to have reached a maximum value in four hours. It is clear that soils at different *p*H values represent structures which, if not permanent, are at least stable for a reasonable length of time, i.e. 50 days.

The effect of *p*H value on dispersion is also brought out quite clearly from the above data (Table I) which shows that the differences in dispension at different *p*H values are maintained even on heating for 10 hours after keeping for 50 days.

In order to see if this state of aggregation is only confined to the clay fraction or to the whole of the soil including coarser fractions as well, complete mechanical analyses up to 0·06 mm. particles were determined after leaving P.C. 13 soil with increasing amounts of alkali in 2 per cent suspensions for three weeks. The results are given in Table II and show that the relation between *p*H and dispersion is the same whatever size of particle is taken into consideration. In other words, the alkali affects all the fractions equally. It would seem as if clay is uniformly distributed throughout the entire soil and as dispersion increases, each fraction contributes a share of clay proportional to size or surface.

TABLE I

Rate of dispersion of P. C. 13 H-soil at different pH *levels*

*p*H (taken after 48 hours)	Per cent (<0·005 mm.) particles after keeping for various intervals of time													
	4 Hours	8 Hours	12 Hours	24 Hours	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	14 Days	30 Days	50 Days	50 days after heating for 10 hours
5·90	6·2	7·6	6·5	6·2	8·4	8·3	9·8	9·4	9·6	9·5	9·5	11·6	12·7	12·7
6·62	9·6	9·7	10·0	10·3	11·7	12·5	13·4	13·2	13·7	14·3	11·6	17·4	19·2	21·2
7·71	12·9	13·2	13·0	14·3	14·8	15·9	19·1	18·6	18·9	19·6	23·8	25·2	28·0	29·4
7·92	15·3	15·6	15·9	18·5	20·4	21·1	21·6	22·3	23·0	23·5	25·4	27·6	29·1	31·0
8·60	14·9	15·4	16·9	21·7	22·9	23·9	24·1	24·9	26·7	27·3	28·7	32·7	34·4	34·9
9·24	16·6	18·7	21·0	23·1	26·0	27·9	28·2	28·8	30·9	31·0	31·3	33·4	35·8	36·2
9·60	18·8	21·6	23·7	26·7	29·4	31·5	31·9	32·6	32·6	34·1	35·3	36·3	38·0	38·4
9·92	24·6	30·8	34·1	38·7	41·4	42·6	43·0	44·1	45·6	45·8	46·1	47·2	47·2	47·5
10·52	60·5	60·9	60·7	61·3	61·1	62·9	62·7	61·0	60·8	60·3	59·7	60·5	59·7	60·6
10·95	64·2	64·6	65·2	62·3	63·0	62·9	61·9	62·2	61·6	61·2	60·9	61·2	61·6	62·3

TABLE II

Complete mechanical analysis of P. C. 13 A.T. at different pH values (after 3 weeks keeping)

pH	Quantity of N/10 NaOH added to 50 gm. of soil	0·06 mm.	0·04 mm.	0·02 mm.	0·01 mm.	0·008 mm.	0·005 mm.	0·002 mm.
5·55	6	58·0	52·0	37·5	31·6	30·4	27·7	23·5
6·16	15	66·3	59·2	51·4	42·6	39·4	36·3	31·3
6·60	20	68·0	64·4	54·3	45·8	43·6	38·4	35·0
7·15	24	71·8	68·0	55·0	47·2	46·9	42·2	37·5
7·45	28	72·9	69·1	59·7	51·2	48·7	44·8	39·6
8·25	34	79·3	73·8	66·2	54·1	51·7	47·3	43·2
9·40	40	83·0	81·3	68·9	57·5	56·5	51·5	44·3
9·95	50	83·8	82·7	74·0	64·2	63·4	58·2	51·9
10·80	70	84·4	82·9	77·7	65·9	64·4	59·2	54·3
11·10	100	85·4	83·5	77·2	67·4	65·4	61·4	57·2

EFFECT OF THE NATURE OF EXCHANGEABLE IONS ON DISPERSION

Increasing amounts of various hydroxides, were added to a H-soil (undispersed) and dispersion measured at every step by determining particles of 0·005 mm. diameter with the Chainohydrometer. The total quantity of alkali added in this case was a little more than generally required for the maximum dispersion, the reason for which will be explained presently. The results are given in Table III. The greater efficiency of Na and Li ions is apparent. This soil requires approximately 60-70 c.c. of N. alkali for 50 gm. to bring it to pH 10·8. When the addition of alkali is pushed still further a slight increase in dispersion is noticed which continues until flocculation takes place. This gradual rise is most probably due to the partial breakdown of the alumino silicates. It might be pointed out that the quantity of alkali added was subtracted from the weight of the suspended matter in every case.

TABLE III

Effect of the nature of exchangeable ions on dispersion

M. E. of various alkalies added to 50 gm. of soil	Lithium		Sodium		Potassium		Ammonium		Calcium		Magnesium	
	pH	Percentage 0·005 mm.	pH	Percentage < 0·005 mm.	pH	Percentage < 0·005 mm.	pH	Percentage 0·005 mm.	pH	Percentage < 0·005 mm.	pH	Percentage < 0·005 mm.
10	6·19	16·1	6·15	9·2	6·05	4·2	6·0	5·3	5·2	5·0	4·88	5·1
20	8·04	32·2	8·02	18·3	8·00	5·6	7·8	7·3	6·0	5·8	6·80	6·2
30	9·30	42·0	9·28	28·2	9·35	5·8	9·2	9·5	7·0	6·6	8·20	7·28
40	10·06	52·7	10·02	40·2	10·20	7·5	9·38	11·8	8·0	6·7	8·70	9·14
50	10·36	56·8	10·30	49·4	10·46	11·8	9·42	14·6	8·6	7·6	8·86	9·69
60	10·62	59·5	10·58	57·5	10·80	13·5	9·46	15·5	8·8	7·9	9·12	10·30
70	10·76	59·6	10·74	59·1	10·90	17·8	9·44	18·0	9·0	7·6	9·20	10·68
80	11·12	60·0	11·12	60·8	11·18	25·7	9·42	20·0	8·98	7·2	9·54	10·80
90	11·18	61·3	11·18	63·1	11·24	27·9	9·54	21·8	9·10	6·0*	9·60	6·55*
100	11·18	61·4	11·18	63·2	11·26	31·0	9·52	23·1	9·16	4·0	9·72	1·96
110	11·25	63·9	11·28	63·9	11·34	30·6	9·58	22·8	9·18	3·4	9·70	1·76
120	11·28	61·8	11·29	67·8	11·36	34·2	9·64	24·5	9·20	3·0	9·74	1·00
130	11·30	61·5	11·30	68·3	11·44	32·8	9·70	26·25	...	...	9·70	...
140	11·32	62·9	11·37	71·6	11·40	23·1*	9·66	26·85	...	...	...	...
150	11·60	64·9	11·55	Flocculates	11·66	15·4	9·80	26·80	...	...	...	...

*Flocculation begins at this point

Complete mechanical analysis of P. C. 13 soil dispersed with different bases was also done. Sixty milli equivalents of alkali were added to 50 gm. of the H-soil in every case and suspensions left for three weeks after which they were mechanically analysed. The results are given in Table IV. It is seen that the effect of different ions on dispersion is similar to the effect of various pH values (Table II).

In the experiments described above, the H-soil used was in the dry and therefore undispersed state. It is known that if a dispersed H-soil is taken and the various ions introduced into the complex by the addition of equivalent amounts of various hydroxides, the dispersion, as regards conventional clay, is unaffected by the nature of the exchangeable ion [Puri, 1930]. However, it is quite likely that such differences might appear

TABLE IV

Complete mechanical analysis of P. C. 13 A.T. dispersed with different bases (after three weeks keeping)

(60 m.e. of alkalies were added to 50 gm. of soil)

	0·06 mm. per cent	0·04 mm. per cent	0·02 mm. per cent	0·01 mm. per cent	0·008 mm. per cent	0·005 mm. per cent	0·002 mm. per cent
Li	82·9	79·1	76·9	66·4	64·8	60·1	55·3
Na	82·4	79·7	75·4	66·6	64·1	60·7	55·0
K	52·2	43·3	27·8	17·4	17·1	12·4	6·8
NH_4	57·42	47·10	36·7	23·8	21·2	17·0	14·50
Ca	48·45	35·10	25·6	10·2	9·0	8·0	4·80
Mg	55·40	41·90	28·0	14·6	14·0	10·4	6·00

in the case of ultra-clay. Two soils, P. C. 13 and 123 were used for this study. These soils represented two distinct types as regards their ultra-mechanical analysis. As lithium ions give the highest dispersion, the soils were first completely dispersed with LiOH. They were then treated with *0·05 N*.HCl to remove all the bases and then without drying they were shaken with equivalent amounts of various hydroxides and the size distribution of particles determined as usual by the pipette method. The results are given in Table V. It is seen that there is practically no influence of the nature of the ion down to particles of 0·00043 mm. diameter. The difference becomes marked only in the case of 0·000177mm. particle and even then only as regards monovalent and divalent ions with the exception of H which behaves more like the divalent ions. Another observation made in this connection was that single base soils containing divalent ions showed a tendency to become flocculated in the course of time. This is indicated in Table I along with the particular fraction where it was noticed. These results are interesting in showing that the only stable suspensions are the saloids of alkali metals, others tending to flocculate in the course of time.

TABLE V

Ultra-mechanical analysis of soils with different ions

Nature of ions	Percentage of particles below various sizes				
	0·002 mm.	0·001 mm.	0·00043 mm.	0·00029 mm.	0·000177 mm.
P.C. 13 Soil—					
Ca	56·46	52·83	40·66	27·66(F)	..
Ba	55·72	38·42(F)	..	..	..
Sr	53·70	51·53	43·33	37·93	28·07(F)
Mg	52·70	50·00	40·11	37·84	24·73(F)
H	53·40	49·83	43·60	38·20	28·40(F)
NH_4	54·05	50·67	44·23	42·73	42·57
Na	54·16	53·60	46·53	46·30	44·86
K	53·95	53·30	42·86	43·73	40·63
Li	54·05	53·83	46·33	43·57	42·46
P.C. 123 Soil—					
Ca	75·60	74·58	57·20	38·35(F)	14·70(F)
Ba	76·35	74·70	58·70	49·20	9·10(F)
Sr	74·10	74·95	29·00(F)	..	..
Mg	75·65	73·05	61·30	49·90	26·15(F)
NH_4	77·40	73·90	56·55	49·50	38·00
Na	75·15	73·85	57·65	49·35	40·20
K	78·05	74·20	58·25	50·60	39·35
Li	77·65	75·45	59·55	51·80	42·65

Hydration of soil colloids—a factor in clay determination

The high dispersion of soil colloids in the presence of Li and Na ions has been generally ascribed to the hydration of these ions. This is quite conceivable as the association of these ions with water molecules could easily overcome the cohesive forces binding the particles together. The hydration may have the effect of decreasing the density thus making them lighter or increasing the friction between the surface of particles and water. This will have the effect of lowering the rate of settling, so that if no account is taken of these factors and settling velocities calculated according to Stokes Law, the pipetting in the mechanical analysis will be made 'too soon' and a portion of the particles of higher diameters will be included, resulting in a higher value for clay. It is an important consideration, because if it is so it will be necessary to look upon some of these estimations in the presence of highly hydrated ions as 'apparent' clay. It has already been seen that a completely dispersed clay is unaffected by the nature of the exchangeable ion provided it is not allowed to dry (Table V). All the monovalent ions, which are admittedly hydrated to varying extents, show the same percentage of clay down to 0·000177 mm. particles. Hydration, therefore, cannot be a factor influencing the settling velocities of these particles. There is another method of throwing light on this point. Clay can be determined at higher temperature, and if hydration is playing any part, there should be a decrease in the clay content due to dehydration. P. C. 13 and 123 soils were chosen for this experiment, as they had the highest base exchange capacity, and, therefore, likely to show the maximum effect of hydration if any. The soils were first brought to a state of maximum dispersion and then various ions introduced after acid treatment as described in the above paragraph. Clay (<0·002 mm.) was determined at three different temperatures, the highest being 64°C. in the case of P. C. 13 and 58°C. in the case of P. C. 123. The results given in Table VI leave no doubt that, whatever effect the hydration may have in breaking up the aggregates, it has no influence on the settling velocities. It is remarkable that Stokes' Law is applicable over such a wide range of temperature in the case of the conventional clay fraction.

Effect of temperature on dispersion

Effect of temperature on dispersion at different pH values was studied by keeping a H-soil with increasing amounts of NaOH in thermos flasks for 24 hours and also by shaking mechanically for the same period. There was a change of temperature of about 5°C. during the period the suspensions were kept or shaken. The results are given in Table VII and show that an increase in temperature leads to a higher dispersion at all pH values, the maximum difference being shown at the highest pH value when the suspension was not shaken. The maximum value, however, showed little difference when the suspensions were shaken.

The same effect is shown in a more striking manner in Table VIII in which the rate of dispersion of the soil at two temperatures is re-recorded. It is seen that at 35°C. the soil is completely dispersed in about 4 hours whereas at 11°-12°C. it takes no less than six days to reach the same state of dispersion.

Table VI

Effect of temperature on the clay content of soils with different ions

Nature of ions	Percentage of clay (0·002 mm.)		
P. C. 123 Soil—	25°C.	1°C.	58°C.
Barium	78·80	74·90	73·40
Calcium	78·40	76·50	75·15
Strontium	76·20	76·85	73·80
Magnesium	75·40	77·80	74·90
Hydrogen	73·00	75·05	72·80
Ammonium	77·05	77·85	71·20
Potassium	76·40	74·60	73·85
Sodium	78·80	75·30	74·45
Lithium	79·55	77·10	74·90
P. C. 13 Soil—	24°C.	1°C.	64°C.
Barium	55·70	55·00	Flocculates
Calcium	53·90	52·00	49·57
Strontium	54·90	53·70	54·13
Magnesium	54·57	53·20	52·15
Hydrogen	53·87	51·23	50·83
Ammonium	52·83	50·87	53·33
Potassium	53·57	52·00	53·53
Sodium	56·20	53·80	55·57
Lithium	56·37	52·73	54·23

Effect of dilution on dispersion

Effect of soil/water ratio on the physico-chemical properties of the suspension such as the pH value and conductivity are well known. In order to complete the analogy between clay suspensions and solutions of weak electrolytes the effect of dilution on soil dispersion must be known. 12 gm. portions of a highly clayey H-soil were dispersed at different pH values by keeping in contact with 200, 400, 600, 800 and 1,000 c.c. of water for 10 days, no mechanical shaking being given. After that the volume was made 1,200

TABLE VII

Effect of temperature on dispersion at different pH *values*

Milli-equivalents of NaOH added to 12 gm. of soil	*p*H (Mean of 4 readings)	A. No shaking was given. The samples were kept at their respective temp. for 24 hours. Percentage < 0·005 mm. particles at various temperatures				*p*H (Mean of 4 readings)	B. Samples were shaken for 24 hours at their respective temperatures. Percentage < 0·005 mm. particles at various temperatures			
		8-12°C.	17-22° C.	28-33° C.	38-44°C.		9-14°C.	19-25°C.	30-35°C	39-49°C.
1·5	6·3	9·4	13·4	15·4	17·0	6·2	28·2	29·8	32·8	32·2
3·5	7·05	19·2	21·6	24·0	28·4	7·05	31·6	33·6	36·0	36·6
5·0	9·05	25·6	27·6	29·4	32·4	8·00	34·6	37·0	39·6	39·4
6·5	9·9	27·6	29·8	31·6	36·0	9·2	42·6	46·0	47·6	49·6
9·0	10·55	29·2	33·6	37·0	39·6	10·15	50·2	54·4	55·6	55·8
11·0	10·86	29·6	35·8	40·8	42·8	10·65	55·4	56·4	59·6	60·8
16·5	11·20	37·0	40·8	41·6	50·0	11·15	59·0	58·6	58·4	61·4
25·0	11·56	41·5	45·9	49·6	62·6	11·52	57·9	58·9	58·1	62·1

TABLE VIII

Effect of temperature on rate of dispersion

Time	Percentage 0·005 mm. particles at *p*H 11·0	
	35°C.	11-12°C.
4 hours	64·2	..
8 hours	64·6	26·6
12 hours	65·2	28·8
24 hours	62·3	32·1
48 hours	63·0	39·1
3 days	62·9	..
4 days	61·9	49·3
5 days	62·2	54·8
6 days	61·6	58·2
7 days	61·2	60·0
14 days	62·2	61·7

c.c. in every case to give 1 per cent suspension. The results are recorded in Table IX. It will be seen that the effect of dilution is not apparent up to *p*H 9·82 but at higher *p*H values the higher dilutions give greater dispersion. The soil used for this experiment was extremely sensitive to *p*H changes as regards dispersion and therefore particularly suited for the purpose. These results again point to the analogy between solutions of weak electrolytes and clay suspensions. The increase in dispersion on dilution fits in well with the increase in activity of electrolytes on dilution.

SUMMARY

The effect of *p*H value, the nature of the exchangeable base, temperature and dilution on soil dispersion was studied. The *p*H value is by far the most important factor. The state of aggregation of the soil reached at different *p*H values represents a comparatively stable structure which undergoes very little change even on keeping for 50 days or heating to a temperature of 60°-70°C. Sodium and lithium are the only bases which give maximum dispersion. The effect of rise in temperature is similar to increase in dilution both leading to enhanced dispersion.

Table IX

Effect of dilution on dispersion at different pH *values*

(Soil No.123—A. T.—1 per cent suspension was prepared)

(After the addition of alkali samples were kept for 10 days. No shaking was given)

Quantity of N. NaOH added to 12 gm. of soil	pH (taken after 10 days)	Volume c.c.	0·06 mm. per cent	0·02 mm. per cent	0·01 mm. per cent	0·005 mm. per cent	0·002 mm. per cent
		200	75·85	51·20	38·8	35·2	33·0
		400	77·0	54·8	41·6	36·4	35·6
3 c.c. . .	9·20	600	74·4	51·6	39·2	34·8	35·3
		800	76·6	49·0	38·8	34·8	33·0
		1000	76·6	48·8	38·9	34·6	33·2
		200	83·6	58·4	48·8	45·6	45·5
		400	82·4	60·8	52·0	47·6	45·3
5 c.c. . .	9·82	600	83·2	59·8	51·0	47·1	46·4
		800	82·9	56·8	48·4	45·0	44·8
		1000	..	..	..	..	..
		200	84·6	66·2	62·2	56·6	56·3
		400	85·1	65·6	64·3	58·2	57·9
8 c.c. . .	10·36	600	87·2	74·6	70·6	67·4	65·9
		800	88·4	75·4	71·9	67·9	67·7
		1000	89·0	76·6	72·4	68·4	68·2
		200	87·90	74·8	68·8	62·5	61·7
		400	89·8	79·2	74·4	72·4	71·0
16 c.c. . .	11·40	600	92·05	83·8	82·0	80·0	78·8
		800	92·9	83·0	81·7	79·4	78·8
		1000	93·6	84·8	83·0	81·9	80·4

The hydration of ions has apparently no effect on the settling velocities of soil particles as calculated from the Stokes' Law.

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STUDIES IN SOIL DISPERSION

III. EFFECT OF VARIOUS PRELIMINARY TREATMENTS ON ULTRA-MECHANICAL ANALYSIS OF SOILS

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A GOOD deal of work has been done on the effect of preliminary treatment of the soil on its mechanical analysis. Very little, however, is known about the effect of such treatment on its ultra-mechanical analysis. It is not unlikely that some of the more drastic treatments might result in a partial destruction of some of the finer fractions while not affecting the percentage of conventional clay. Attention was therefore directed mainly to those treatments which are likely to prove too drastic.

DESTRUCTION OF HUMUS

Humus is known to play an important part in the dispersion of soils. It acts as a cementing material, thereby, preventing the dispersion of soil aggregates. Robinson [1932] found that certain Welsh soils rich in organic matter did not disperse fully even after the removal of exchangeable calcium and calcium carbonates. He suggested preliminary oxidation of organic matter with boiling H_2O_2 solution. This method was later adopted as the International method of preliminary treatment of soils for mechanical analysis. Hydrogen peroxide, however, was found to be not quite a suitable reagent on account of its being expensive as well as troublesome especially in hot climates. Crowther and Troell [1932] suggested the use of cold solution of sodium hypobromite, while Chakraborty [1935] advocated the use of alkaline potassium permanganate. Puri and Sarup [1937, 2] introduced a few modifications in the details of Chakraborty's method and also showed [1937, 1] that the efficiency of alkaline $KMnO_4$ for oxidising organic matter was greater than that of H_2O_2.

The use of alkaline permanganate, however, may be objected to on the ground that it is too drastic and might easily result in the destruction of a part of the inorganic soil colloids. This adverse effect would naturally be confined to particles of ultra-clay. It was, therefore, of interest to study the effect of this treatment on the ultra-mechanical analysis. Eight soils were used for this study. These soils were not rich in humus as the object was to find out what effect the treatment had on the inorganic colloids. The soils after being freed from exchangeable bases were treated with alkaline $KMnO_4$ in accordance with the directions given by Puri and Sarup [1937, 2] and were dispersed by shaking them for 24 hours in presence of sufficient NaOH to raise the *p*H value to 10·8 [Puri and Manohar Lal, 1938]. Ultra-mechanical analyses of these soils before and after the treatment were determined by the Micro Pipette technique [Puri and Puri, 1941]. The results given in Table I show that oxidation with alkaline $KMnO_4$ has not produced any striking difference in the ultra-clay.

From the results it will also be seen that the preliminary destruction of organic matter is not necessary when the acid-treated soils are dispersed by the addition of sufficient amount of NaOH. In order to find out if it is also true in the case of soils containing excess of humus, 10 soils, rich in organic matter, were freed from exchangeable bases and dispersed by the addition of NaOH both before and after the preliminary treatment with alkaline $KMnO_4$. The *p*H value of each suspension was brought to 10·8. The results recorded in Table II reveal the following facts:

(1) When soils are not freed from humus, consistently higher values are obtained for all the fractions.

(2) The difference in the two sets of values obtained for a soil is of the order of the percentage of humus present in that soil. It is interesting to note in this connection that humus itself in alkaline solutions has got no ultra-mechanical analysis and all particles appear more or less to be of uniform diameter up to the limit to which the ultra-mechanical analysis can be pushed. This will be clear from the results of an experiment (Table III) in which humic acid was peptised with NaOH and then subjected to ultra-mechanical analysis.

(3) Humus on account of its solubility in NaOH no longer acts as a cementing material if dispersion is brought about by the HCl—NaOH method.

(4) In order to obtain the correct and not unduly high values of mechanical analysis of the mineral colloids preliminary destruction of organic matter in case of soils rich in humus is essential.

TABLE I

Effect of employing alkaline $KMnO_4$

Soil No.	Per cent humus	Treated or untreated with $KMnO_4$	Summation percentages of particles of various diameters in mm.					
			0·001	0·00063	0·00025	0·0001	0·000063	0·00004
116	1·2	Untreated . .	24·8	22·4	18·1	12·7	7·6	6·0
		Treated . .	23·3	20·4	16·9	11·0	6·6	5·6
183	0·5	Untreated . .	8·4	7·0	6·1	4·1	3·5	0·8
		Treated . .	10·2	9·2	8·3	3·5	3·1	1·2
242	0·8	Untreated . .	15·8	13·5	11·2	7·0	5·6	4·5
		Treated . .	15·2	13·2	11·9	5·4	4·0	3·2
243	0·5	Untreated . .	11·1	10·0	8·0	3·6	2·6	2·0
		Treated . .	9·5	8·3	6·3	4·5	2·0	2·0
244	0·2	Untreated . .	37·0	29·0	20·1	12·4	9·0	5·2
		Treated . .	36·5	30·8	21·5	12·6	9·6	7·6
245	0·5	Untreated . .	30·1	28·6	20·5	12·6	10·2	9·8
		Treated . .	34·8	29·0	20·9	13·5	9·6	7·8
250	0·45	Untreated . .	8·2	8·0	6·0	4·5	4·0	3·6
		Treated . .	10·4	9·0	7·2	3·8	3·1	2·8

(5) The alkaline permanganate method of destroying organic matter does not affect the mineral colloids and therefore cannot be considered as too drastic a preliminary treatment of the soil for mechanical analysis.

TABLE II

Comparison of ultra-mechanical analysis of soils with and without the destruction of humus

Soil No.	Per cent humus	Humus freed or not	Summation percentages of particles of various diameters in mm.						
			0·002	0·001	0·00063	0·00025	0·001	0·000063	0·00004
M-8	4·5	Humus not freed .	32·8	30·0	26·2	22·6	15·9	12·5	10·8
		Humus freed . .	30·0	27·1	23·8	20·2	12·1	9·0	8·1
M-12	4·1	Humus not freed .	25·6	24·0	20·9	15·1	13·3	10·0	9·5
		Humus freed . .	22·2	19·2	17·2	11·7	9·9	7·2	6·0
M-19	6·3	Humus not freed .	36·6	33·2	27·1	20·0	14·2	12·8	11·2
		Humus freed . .	30·8	27·5	21·8	15·2	11·5	8·0	7·0
M-40	5·25	Humus not freed .	63·0	58·2	45·0	37·3	30·2	22·5	21·5
		Humus freed . .	57·9	52·4	39·2	32·0	25·2	17·2	16·6
M-41	3·77	Humus not freed	66·4	63·4	56·2	44·0	24·5	13·5	9·8
		Humus freed . .	62·1	59·0	52·4	41·8	21·6	10·9	6·8
P-C.2	5·78	Humus not freed .	24·4	20·6	16·1	12·5	11·9	11·2	9·2
		Humus freed . .	18·6	15·2	12·5	9·4	8·8	7·1	5·0
P.C. 3	4·66	Humus not freed .	28·5	23·4	18·9	15·5	14·3	12·2	10·1
		Humus freed . .	23·8	20·5	15·7	12·5	12·1	10·2	7·2
P.C. 5	7·28	Humus not freed .	25·7	23·1	15·9	13·5	15·8	14·6	11·2
		Humus freed . .	18·5	16·8	11·5	7·6	10·0	10·3	6·6
P.C. 6	4·67	Humus not freed .	30·2	..	22·9	15·2	15·8	14·4	11·8
		Humus freed . .	25·5	..	16·3	12·9	12·2	11·0	8·1

TABLE III

Humic acid after peptising it with NaOH
(pH of the solution = 9·3)

Particle size in mm.	Percentages
0·002	90·8
0·001	89·7
0·00063	90·2
0·0001	90·8
0·00004	90·4

PRELIMINARY ACID TREATMENTS

It has been shown elsewhere that in order to get maximum dispersion in the region of ultra-clay the methods involving acid treatments are the only ones that are most effective [Puri, Puri and Manohar Lal, 1938]. These methods, however, may be regarded as too drastic on the ground that they result in the dissolution of aluminium and iron. In order to find out how far this objection is valid, three typical soils were leached with increasing amounts of HCl of varying concentrations. The soils were afterwards washed with water until free from Cl ions and then dispersed by the addition of sufficient NaOH to bring the pH value of the suspensions to 10·8 and shaking overnight. The results given in Table IV clearly show that even after the removal of exchangeable bases prolonged leaching of the soil with the acid of much higher strength than that generally recommended for the purpose will produce no change in the results of ultra-mechanical analysis. The soil colloids, in fact, as far as can be judged from the behaviour of these three typical soils, are quite stable and resist the action of dilute HCl leaching. Leaching with N. HCl however, produces slight changes, but acid of this strength is never recommended in any preliminary treatment for dispersion.

HEATING SOILS TO VARIOUS TEMPERATURES

Effect of heating soils to various temperatures on their physico-chemical properties has been studied by Puri and Asghar [1940]. They found that heating at 400°C. causes fusion of clay particles resulting in the formation of stable aggregates which could not be distinguished from coarser fractions. As at temperatures below 400°C., the summation curves showed general similarity in the region of clay, silt and sand and it was at 400°C. and above this temperature that shift in the curve as a whole was noticed, this temperature (400°C.) was regarded by these authors as the 'fusion temperature of colloidal particles'*. This statement could only be justified if ultra-mechanical analysis, i.e. the analysis within the colloidal region itself could be shown to have been not affected below this temperature. Because it is quite likely that the ultra-clay might be affected even at a much lower temperature than 400°C.

Two acid-treated soils, P. C. 13 and 123 (one of which, namely, P.C. 13, was the same as that used by Puri and Asghar [1940]) were heated to various temperatures and then dispersed by the addition of enough NaOH to bring the pH value of the suspensions to 10·8. The results of complete mechanical and ultra-mechanical analysis are shown in Tables V and VI. It would be seen that while heating up to 300°C. has produced no difference up to 0·001 mm., it has appreciably affected the finer fractions, the effect becoming more and more pronounced as we go farther and farther into the regions of ultra-clay.

Heating up to 100°C. produces no alteration even in the region of ultra-clay but heating above this temperature tells its effect. It starts cementing finest particles first and with further rise of temperature particles coarser and coarser begin to aggregate together. We may thus regard heating the soil even at 200°C. to cause the 'fusion of colloidal particles'. It would also be seen that in the case of P. C. 123 not only abrupt change in clay percentage appears at 500°C. (instead of at 400°C. as in case of P. C. 13) but also the differences in the regions of ultra-clay are less pronounced for temperatures below 500°C. Since this soil is less colloidal in properties than P. C. 13 soil, this difference, which is of degree only, is to be expected.

As a result of 'fusion' of colloidal and coarser particles the specific surface of the soils on heating will decrease considerably. The values of specific surface of these soils at different temperatures are given in Table VII. The methods of calculating specific surface are discussed elsewhere [Puri, Balwant Rai and Malhotra, 1944].

*It must be understood that the word 'fusion' is used only in a special sense namely, cementing together of the particles

TABLE IV

Effect of preliminary acid treatments

Description of the sample	Percentages of particles below various limiting diameters in mm.						
	0·002	0·001	0·00063	0·00025	0·0001	0·00006	0·00004
P. C. 6 Soil leached with N/20 HCl till free from exchangeable bases	33·8	31·3	28·2	23·4	18·2	17·0	14·5
P. C. 6 Soil leached with N/20 HCl till free from exchangeable bases further leached with 500 cc. of N/20 HCl	34·2	32·2	29·8	24·5	18·2	18·8	14·2
P. C. 6 Soil leached with N/20 HCl till free from exchangeable bases further leached with 1000 cc. of 1N/20 HCl	34·8	32·4	29·6	24·9	19·1	17·2	14·6
P.C. 6 Soe leached with N/20 HCl till free from exchan able bases further leached with 500 cc. of N/5 Cl	34·4	32·1	29·0	25·1	18·5	16·9	13·8
P.C. 6 Soil leached with N/20 HCl till free from exchangeable bases further leached with 1000 cc. of N/5 HCl	33·7	32·2	29·4	24·6	17·8	16·8	14·4
P.C. 6 Soil leached with N/20 HCl till free from exchangeable bases further leached with 500 cc. of N-HCl	33·5	31·2	28·2	23·2	16·0	15·4	12·6
P.C. 6 Soil leached with N/20 HCl till free from exchangeable bases further leached with 1000 cc. of N.HCl	32·4	31·0	26·6	23·5	15·6	14·5	12·6
P.C. 13 Soil leached with N/20 HCl till freed from bases	60·1	57·7	52·5	49·0	41·5	36·7	27·2
P.C. 13 Soil leached with N/20 HCl till freed from bases further leached with 500 c.c. of N/20 HCl	60·5	56·0	51·4	48·6	40·8	36·2	28·1
P.C. 13 Soil leached with N/20 HCl till freed from bases further leached with 1000 cc. of N/20 HCl	61·5	56·6	52·2	49·2	44·0	36·4	27·8
P.C. 13 Soil leached with N/20 HCl till freed from bases further leached with 500 cc. of N/5 HCl .	59·8	56·2	52·0	48·2	41·4	36·6	27·1
P.C. 13 Soil leached with N/20 HCl till freed from bases further leached with 1000 cc. of N/5 HCl	58·7	55·8	50·8	46·2	39·5	34·5	26·6
P.C. 13 Soil leached with N/20 HCl till freed from bases further leached with 500 cc. of N.HCl .	56·9	54·8	49·4	45·8	40·0	31·8	25·2
P.C. 13 Soil leached with N/20 HCl till freed from bases further leached with 1000 cc. of N-HCl .	57·4	55·1	49·2	45·8	39·6	31·6	25·5
P.C. 123 Soil leached with N/20 HCl till freed from bases	85·5	84·2	74·4	52·5	25·8	14·2	12·9
P.C. 123 Soil leached with N/20 HCl till freed from bases further leached with 500 cc. of N/20 HCl	84·6	83·6	74·0	49·4	24·2	13·5	11·5
P.C. 123 Soil leached with N/20 HCl till freed from bases further leached with 1000 cc. of N/20 HCl	83·8	82·0	72·6	46·2	22·2	14·0	12·6
P.C. 123 Soil leached with N/20 HCl till freed from bases further leached with 500 cc. of N/5 HCl	86·2	83·6	74·2	48·8	24·6	14·5	13·0
P.C. 123 Soil leached with N/20 HCl till freed from bases further leached with 1000 cc. of N/5 HCl	86·0	91·0	72·0	48·6	26·2	13·5	12·0
P.C. 123 Soil leached with N/20 HCl till freed from bases further leached with 500 cc. of N-HCl	80·1	79·3	69·8	44·1	23·5	12·1	10·3
P.C. 123 Soil leached with N/20 HCl till freed from bases further leached with 1000 cc. of N-HCl	78·2	75·3	63·8	42·6	23·0	12·0	10·1

TABLE V

Effect of igniting P.C. 13 A.T. soil to various temperatures

Description of the sample	Percentages of various limiting diameters in mm.										
	0·06	0·02	0·01	0·005	0·002	0·001	0·00063	0·00025	0·0001	0·00006	0·00004
1. Air-dried sample	90·8	82·8	70·6	63·6	60·3	57·7	52·9	49·2	41·0	35·7	27·2
2. Heated to 100°C.	89·5	82·9	72·2	65·0	59·2	56·7	54·4	49·1	43·2	37·9	28·2
3. Heated to 200°C.	91·4	82·5	73·5	66·2	61·2	57·2	54·2	41·7	27·2	22·1	19·2
4. Heated to 300°C.	90·8	82·7	72·8	65·2	57·5	54·4	49·6	36·5	17·3	16·0	11·2
5. Heated to 400°C.	61·8	41·4	30·2	24·5	19·5	18·2	16·4	14·7	13·5	11·0	19·5
6. Heated to 500°C.	45·6	26·2	19·1	14·1	11·2	8·4	7·6	6·3	4·8	4·5	3·9
7. Heated to 600°C.	45·5	22·6	16·4	12·2	8·5	6·8	5·4	5·5	3·4	2·9	2·5
8. Heated to 700°C.	41·0	21·2	15·4	10·6	6·0	5·4	5·0	4·2	2·8	2·2	1·7
9. Heated to 800°C.	41·0	22·2	14·7	10·5	6·5	5·8	5·2	2·8	2·4	1·9	1·0
10. Heated to 900°C.	40·5	18·2	11·9	8·2	6·4	4·2	3·2	1·2	0·9	*nil*	*nil*

TABLE VI

Effect of heating P.C. 123 A.T. to various temperatures

Description of the sample	Percentages of various limiting diameters in mm.										
	0·06	0·02	0·01	0·005	0·002	0·001	0·00063	0·00025	0·0001	0·000063	0·00004
1. Air-dried sample (No heating)	98·8	93·2	90·2	89·3	85·5	81·5	74·2	52·2	25·8	18·6	12·4
2. Heated to 100°C.	99·2	91·2	89·1	86·4	86·9	81·6	73·6	50·8	25·5	18·3	12·8
3. Heated to 200°C.	99·0	91·2	89·6	87·8	86·6	81·8	75·0	52·3	22·0	16·2	11·9
4. Heated to 300°C.	99·0	92·5	90·8	90·0	85·9	77·4	70·0	47·0	20·5	14·2	10·5
5. Heated to 400°C.	97·0	92·6	90·4	86·8	80·9	68·9	54·5	28·5	16·8	11·2	7·5
6. Heated to 500°C.	72·8	52·8	45·2	39·2	20·5	26·6	21·6	13·6	10·5	9·0	7·0
7. Heated to 600°C.	61·2	36·2	29·1	23·8	17·8	16·0	12·6	9·4	6·6	5·1	4·6
8. Heated to 700°C.	52·4	29·0	20·4	16·2	9·5	9·2	5·8	5·1	4·1	3·9	3·2
9. Heated to 800°C.	48·1	25·2	17·1	14·0	7·8	5·9	3·8	3·6	3·5	3·2	2·6
10. Heated to 900°C.	45·6	22·4	14·8	11·0	4·8	4·1	3·6	3·0	2·6	2·2	1·8

TABLE VII

Specific surface of P. C. 13 and 123 soils when heated to different temperatures

Temperature to which heated	Specific surface in sq. cm. × 10^4	
	P.C.13A.T	P.C.123A.T
Air-dried	37·5	23·7
100°C.	38·2	23·7
200°C.	26·6	22·3
300°C.	18·0	20·3
400°C.	12·3	15·2
500°C.	4·9	10·4
600°C.	3·3	6·4
700°C.	2·4	4·2
800°C.	1·8	3·3
900°C.	0·6	2·4

DISPERSION OF IGNITED SOILS AT *p*H VALUES LOWER THAN 10·8

It will be seen from Table V that samples of P. C. 13 (acid-treated) heated at 100°C., 200°C. and 300°C. when dispersed at *p*H 10·8 give almost identical values for clay percentage. In order to find out whether these samples will also disperse to equal extents at *p*H levels lower than 10·8, their 2 per cent suspensions were prepared and increasing amounts of N. NaOH were added after every 48 hours. After each addition the cylinders were shaken by hand just for a couple of minutes and then kept aside for 48 hours, after which percentage of clay (0·002 mm.) was determined by the Chaino-hydrometer [Puri and Puri, 1939]. The result recorded in Table VIII show that at low *p*H values there is difference in clay percentage which decreases with the rise in *p*H value till it disappears at the

proper pH level (10·8). This behaviour may be expected since the aggregation of ultra-clay particles which has been shown to take place at 200°C. and above would tend to inhibit dispersion to a certain extent. But as soon as pH of the suspension is raised to 10·8, the discrepancy in dispersion, as measured on the basis of conventional clay, disappears. This fact incidently suggests the significance to a marked degree of bringing the pH of the suspensions to 10·8 in order to get maximum dispersion [Puri and Manohar Lal, 1938].

Effect of grinding on dispersion

Grinding was one of the earliest methods of dispersion. In the present experiments P.C. 13 acid-treated soil was subjected to grinding in a pestle and mortar for different intervals of time varying from 15 min. to 12 hr. The ground material in every case was brought to pH 10·8 by the addition of NaOH and shaken overnight. The results of mechanical and ultra-mechanical analysis are recorded in Table IX. It is seen that silt and clay particles are considerably affected by grinding while the ultra-clay fractions up to 0·00025 mm. undergo only slight increase and fractions finer than this remain practically unchanged.

Table VIII

Dispersion of P.C. 13 A.T. heated to different temperatures on the gradual addition of increasing amounts of NaOH

[Percentage of clay (<0·002 mm.) at various temperatures]

Quantity of N. NaOH added to 12 gm. of soil (per cent suspension)	100°C.	200°C.	300°C.
0·0 c.c.	4·4	2·6	2·0
3·0 c.c.	4·8	3·0	2·4
6·0 c.c.	4·8	2·8	3·0
9·0 c.c.	9·4	5·8	3·2
12·0 c.c.	15·0	11·2	4·0
15·0 c.c.	22·6	19·7	10·5
18·0 (pH 10·8)	39·2	38·4	35·9
21·0 c.c.	55·6	56·0	56·2
24·0 c.c.	63·2	62·2	62·0
27·0 c.c.	63·2	61·6	64·1
30·0 c.c.	63·6	62·3	64·1
33·0 c.c.	63·8	63·4	64·5
36·0 c.c.	64·6	65·2	64·9

Table IX

Effect of grinding on mechanical and ultra-mechanical analysis

(P.C. 13 A.T.)

Time of grinding	Percentages of various limiting diameters in mm.										
	0·06	0·02	0·01	0·005	0·002	0·001	0·00063	0·00025	0·0001	0·000063	0·00004
0 min.	85·5	82·2	72·5	65·0	60·5	56·6	52·5	48·5	43·8	37·4	27·2
15 min.	90·5	85·1	74·2	69·2	63·6	60·4	53·9	52·7	44·3	39·9	27·9
30 min.	94·1	89·2	78·5	70·8	65·2	61·6	57·3	53·3	43·9	35·8	28·3
1 hour	95·5	91·5	80·4	71·4	67·8	62·8	56·5	52·8	42·8	37·2	28·6
3 hours	96·0	94·2	85·5	76·0	74·5	63·8	60·3	54·5	41·4	34·8	29·1
6 hours	96·0	94·8	92·8	80·2	76·9	67·5	59·3	54·6	42·7	36·2	27·0
12 hours	99·2	96·8	94·6	86·5	81·6	69·2	59·5	55·0	42·5	36·6	26·8

Table X

Specific surface, base exchange capacity and ammonia absorption of P.C. 13 A.T. soil after grinding for various intervals of time

Time of grinding	Specific surface in sq. cm. ×10⁴	Base exchange capacity (milli. equivalents per 100 gm. of soil)	Ammonia absorption (m. equivalents per 100 gm. of soil)
0 min.	37·5	42·3	30·5
15 min.	38·1	43·1	34·5
30 min.	38·9	43·3	36·2
1 hour	38·7	43·6	39·2
3 hours	38·7	44·6	41·6
6 hours	38·8	46·2	41·9
12 hours	38·8	..	..

The values for specific surface are given in Table X. There is little or no change in surface as this depends to a marked extent on the ultra-clay fractions. There is, however, appreciable increase in the ammonia absorption and some slight increase in the base exchange capacity (Table X). This is probably due to the fact that as coarser fractions are broken down to finer ones, fresh surface are exposed leading to an increase in base exchange properties.

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VARIATION IN THE MEASURABLE CHARACTERS OF COTTON FIBRES VII*

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(A) VARIATION DUE TO IRRIGATION

In the development of the cotton fibre there exist two distinct stages (1) the lengthening phase and (2) the thickening phase. The former covers approximately the first half of the maturation period of the boll and the latter the other half. According to Balls [1930] and others, if during any of these stages a deficiency in the water supply is experienced, the fibres will get either shorter or less thickened according to the occurrence of the water shortage in the lengthening or thickening stages. Hence on *a priori* considerations it appears as if the differences in the water given in the form of irrigation should influence the length, the uniformity of length and the maturity of the fibre. An attempt to study this effect is made in the present work. Recently, Ayyar, Ahmad and Thirumalachari [1940] have shown that considerable differences are effected in the yield of cotton by differential irrigation. Its influence on the spinning value and the fibre properties, however, is not found to be large.

Material and methods

In this study two sets of experiments have been considered on the cotton Co2 (*G. hirsutum*), the first being a field experiment in random replicated plots and the second one a pot-culture experiment. In the field experiment four types of irrigation were given, (i) once a week, (ii) once in two weeks, (iii) once in three weeks, and (iv) no irrigation. In each irrigational treatment three spacings, 4 in. between plants, 9 in., and broadcast sowing were tried. Two such series were studied in the present investigation.

The pot-culture experiment was conducted by Mr N.C. Thirumalachari, to whom thanks are due for the samples. Five replications have been examined for each of the following five treatments: (i) 30 per cent water for first five fortnights, 35 per cent for next four fortnights and 20 per cent afterwards; (ii) 30 per cent for first nine fortnights, and 20 per cent afterwards; (iii) 25 per cent for two fortnights, 35 per cent for seven fortnights and 20 per cent afterwards; (iv) 25 per cent for two fortnights, 35 per cent for five fortnights and 20 per cent afterwards; (v) 25 per cent for first two fortnights, 35 per cent for three fortnights and 20 per cent afterwards.

In the first investigation the fibre properties studied are the fibre length, uniformity of length and fibre maturity. The uniformity of length was assessed by the coefficient of variation of the Balls sorter length distribution. In order that this may be ascertained more accurately the group-length interval was made finer, 1/16 in. in place of the usual 1/8 in. In the pot-culture experiment, besides the above-mentioned properties, the fibre weight was also determined. The maturity was determined by examining five tufts of about 100 fibres each while in the previous case 10 such tufts were tested. The analysis of variance for the maturity percentages was made using the inverse sine transformation.

The results from the two experiments are considered together.

Results

The mean values obtained are given in Table I and the individual results along with the analysis of variance are recorded in Tables II to V.

*Part of a thesis approved for the award of D.Sc. degree by the University of Madras

(a) Mean fibre length

In both the experiments the variance due to variations in the water supplied to the plants is non-significant (Table II). But in both of them the last treatment, which corresponds to the lowest amount of water given, records the lowest mean fibre length, though according to the statistical analysis the decrease is not significant. This treatment in the pot-culture experiment corresponds to 20 per cent water after the first five fortnights. As the lengthening phase of the fibres occurs during this period, the results may be taken as an indication that probably 20 per cent water is not sufficient to develop the fibres to the optimum length. Ayyar, *et al.* [1940] have also found that the influence of differential irrigation on fibre length is small in a similar set of samples. Afzal and Ahmad [1942] find a small improvement of length with more irrigation water in the case of P. A. 4F.

A comparison of the residual errors in the two experiments shows that it is considerably more in the pot-culture experiment, indicating the higher variability exhibited by this kind of work.

(b) Uniformity of fibre length

As it is not valid to analyse the results for the coefficient of variation by the method of variance, the mean values alone may be considered. It will be seen that in the field experiment no-irrigation treatment exhibits a higher coefficient of variation of length. In the pot-culture experiment, on the other hand, there appears to be no definite trend in relation to the quantity of water given.

TABLE I

Variation with irrigation

(Mean of 6 values in Expt. 1 and of 5 values in Expt. 2)

Property	Expt. No.	Treatments				
		I	II	III	IV	V
Mean length (in.)	1 2	0·94 0·90	0·92 0·91	0·92 0·90	0·90 0·91	. . 0·84
Coefficient of variation of length (per cent)	1 2	21·4 20·7	22·3 18·9	22·3 21·9	23·6 20·9	. . 19·8
Fibre weight per cm. 10^{-6} gm.	. . 2	. . 1·70	. . 1·76	. . 1·69	. . 1·67	. . 1·79
Mature fibres per cent	1 2	52 62	52 67	52 63	48 62	. . 73
Immature fibres per cent	1 2	16 15	19 13	18 17	20 16	. . 11

(c) Fibre weight per cm.

These results have been obtained for the pot-culture experiment only.

They show that the variance due to treatments is non-significant (Table IV). The differences between the mean values are also small, showing that the range of water supply dealt with in the present enquiry has induced no differential effect on the fibre weight. Ayyar, *et al.* [1940] find small improvement in fibre weight with increase of irrigation water, but Afzal and Ahmad [1942] find no significant effect in the case of P. A. 4F.

(d) Fibre maturity

In both the experiments the variation due to change in water supplied is not significant (Table V), indicating that the fibre maturity remains unaffected in the present case. Ayyar, *et al.* [1940], however, observe slight improvement of maturity with better water supply. Gulati [1941] finds an improvement of maturity with greater irrigation in the later sowings and no effect in the earlier sowings. Afzal and Ahmad [1942] find that P. A. 4F. showed a tendency for the improvement of fibre maturity with increase of water supplied.

CONCLUSIONS

From the foregoing it appears that in the present set of samples,

(1) the lowest supply of water probably tends to reduce the mean fibre length to a small extent, though it is not statistically significant;

(2) the uniformity of fibre length appears to be less in plots with no irrigation in the field experiment; in the pot-culture experiment no definite trend is indicated;

(3) hardly any variation is effected in the fibre weight; and

(4) no variation is caused in the fibre maturity also.

Campbell, *et al.* [1941], who studied a number of Upland cottons grown under rain-fed and irrigated conditions, sum up by stating that on the whole it appears that any superiority of rain-grown cotton is chiefly connected with cleanliness; these cottons are less wasty and the yarns and fabrics are less neppy.

TABLE II

Mean fibre length in inch

Treatment → / Particulars ↓	I	II	III	IV	V	Analysis of variance: Due to	D. F.	S. S.	M. S.
Field Expt. 4 in. 1	0·95	0·91	0·89	0·92	..	Total	23	0·01793	..
2	0·89	0·98	0·95	0·93	..	Irrigation and no irrigation	1	0·00222	0·00222
9 in. 1	0·92	0·95	0·92	0·89	..				
2	0·97	0·89	0·97	0·91	..	Irrigations	2	0·00041	0·00020
Broadcast 1	0·94	0·90	0·92	0·88	..	Spacings	2	0·00083	0·00042
2	0·94	0·91	0·92	0·91	..	Series	1	0·00135	0·00135
Mean	0·936	0·922	0·919	0·902	..	Residual	17	0·01312	0·000772
Pot-culture Expt. 1	0·95	0·93	0·95	0·93	0·79				
2	0·92	0·86	0·90	0·90	0·72	Total	24	0·05900	..
3	0·87	0·86	0·82	0·87	0·87	Between treatments	4	0·01876	0·00469
4	0·94	0·96	0·95	0·93	0·88				
5	0·83	0·94	0·86	0·90	0·82	Within treatments	20	0·04024	0·002012
Mean	0·902	0·910	0·896	0·906	0·836				

TABLE III

Coefficient of variation of fibre length (per cent)

Treatments → / Particulars ↓	I	II	III	IV	V
Field Expt. . . . . . 4 in. 1	20·8	22·5	24·0	23·0	..
2	23·6	20·7	22·2	22·2	..
9 in. 1	21·8	21·2	22·4	25·3	..
2	20·4	23·3	22·2	22·7	..
Broadcast 1	21·2	23·3	21·7	25·3	..
2	20·4	22·6	21·4	23·1	..
Mean	21·37	22·27	22·32	23·60	..
Pot-culture Expt. . . . . Rep. 1	18·6	19·1	21·2	22·3	18·6
2	21·6	17·1	22·1	20·2	20·7
3	22·2	20·5	21·7	20·5	21·0
4	19·7	18·1	20·9	20·9	19·7
5	21·3	19·7	23·4	20·5	18·9
Mean	20·68	18·90	21·86	20·88	19·78

(B) VARIATION DUE TO SPACING

Three kinds of spacings 4 in., 9 in. and broadcast sowing were tried for the cotton Co2 in each of the four irrigational treatments as already stated. The mean values for the spacings are recorded in Table VI.

It will be seen that none of the properties, mean length, coefficient of variation of length or maturity indicate any variation. The variances are non-significant and the spacings considered in the experiment have produced no effect on the fibre properties studied. Ayyar, *et al.* [1940] have also observed no effect of the spacing in a similar set of samples.

TABLE IV

Fibre weight per cm. in 10^{-6} gm.

Replications	I	II	III	IV	V	Analysis of variance: Due to	D. F.	S. S.	M. S.
1	1·71	1·93	1·79	1·45	1·75	Total . .	24	0·52700	..
2	1·66	1·76	1·87	1·64	1·63	Between treatments	4	0·04898	0·01224
3	1·74	1·79	1·80	1·65	1·69				
4	1·64	1·71	1·31	1·69	1·86	Within treatments	20	0·47802	0·02390
5	1·73	1·62	1·66	1·93	2·00				
Mean	1·698	1·762	1·690	1·672	1·786				

TABLE V

Fibre maturity per cent

Treatments→ Particulars↓	I	II	III	IV	V	Analysis of variance (after inverse sine transformation): Due to	D. F.	S. S.	M. S.
Mature fibres 4 in. 1	59·0	50·3	50·6	51·8	..	Total . .	23	317·120	..
2	45·9	62·1	52·9	44·7	..	Irrigation and no irrigation	1	28·502	28·502
Field Expt. 9 in. 1	42·5	53·7	49·6	42·2	..				
2	59·1	36·0	57·3	48·1	..	Irrigations .	2	0·213	0·106
Broadcast 1	49·2	49·6	49·3	43·1	..	Spacings .	2	22·501	11·250
2	55·3	59·2	52·6	55·1	..	Residual .	18	265·904	14·772
Mean	51·8	51·8	52·0	47·5	..				
Mature fibres 1	65	73	63	51	71	Total . .	24	463·542	..
2	61	64	77	59	74				
Pot-culture Expt. 3	57	58	60	63	74	Between treatments	4	161·026	40·256
4	61	68	51	61	74				
5	65	68	62	75	71	Within treatments	20	302·516	15·126
Mean	61·8	66·2	62·6	61·8	72·8				
Immature						Total . .	23	328·898	..
fibres 4 in. 1	11·9	19·7	22·4	17·7	..				
2	17·0	12·3	15·7	21·4	..				
Field Expt. 9 in. 1	27·1	19·8	17·4	21·5	..	Irrigation and no irrigation	1	11·680	11·680
2	10·7	33·3	14·2	20·7	..				
Broadcast 1	16·0	17·3	22·2	22·5	..	Irrigations .	2	21·278	10·639
2	13·3	13·5	16·0	14·6	..	Spacings .	2	31·365	15·688
Mean	16·0	19·3	18·0	19·8	..	Residual .	18	264·575	14·699
Immature fibres 1	15	9	13	23	13	Total . .	24	282·926	..
Pot-culture Expt. 2	17	16	9	21	11				
3	16	15	22	14	9	Between treatments	4	67·438	16·860
4	12	12	24	13	13				
5	13	11	17	10	11	Within treatments	20	215·488	10·774
Mean	14·6	12·6	17·0	16·2	11·4				

TABLE VI

Fibre characters in different spacings

Property		4 in.	9 in.	Broad-cast		
Mean length (in.)		0·93	0·93	0·92	..	..
Coefficient of variation of length (per cent) . . .		22·4	22·4	22·4	..	..
Mature fibres per cent	Expt. 1	52·1	48·6	51·1	..	..
	Expt. 2	(6 in.) 90·6	(9 in.) 89·9	(12 in.) 90·5	(15 in.) 87·0	(18 in.) 86·6
Immature fibres per cent	Expt. 1	17·2	20·6	17·0	..	..
	Expt. 2	(6 in.) 4·5	(9 in.) 5·0	(12 in.) 5·0	(15 in.) 6·4	(18 in.) 6·3

The results for the fibre maturity in another study may be considered here. The individual results are recorded in Table VII. For the cotton Kpt. 1 five spacings were given with four replications for each spacing. The spacings were 18, 15, 12, 9 and 6 in.

It will be seen that the variations are non-significant, indicating that the different spacings used have no effect on fibre maturity. Gulati [1941] has found some improvement of maturity in double spacing as against single spacing.

TABLE VII

Fibre maturity in different spacings per cent (Kpt. 1)

Maturity	Replications	18 in.	15 in.	12 in.	9 in.	6 in.	Analysis of variance (after inverse sine transformation)			
							Due to	D. F.	S. S.	M. S.
Mature	1	81·3	79·3	91·8	90·1	92·0	Total	19	168·378	..
	2	90·5	90·4	90·5	86·0	89·4				
	3	90·6	88·5	89·1	92·3	90·6	Between treatments	3	43·546	14·515
	4	84·2	89·7	90·5	91·2	90·3	Within treatments	16	124·832	7·796
	Mean	86·6	87·0	90·5	89·9	90·6				
Immature	1	6·5	9·5	4·2	4·4	3·4	Total	19	68·308	..
	2	4·3	5·0	4·8	7·0	5·5	Between treatments	3	16·118	5·373
	3	5·1	5·4	5·9	4·0	4·2				
	4	9·3	5·3	5·0	4·6	4·9	Within treatments	16	52·190	3·262
	Mean	6·3	6·4	5·0	5·0	4·5				

Summing up it may be stated that none of the different spacings considered in the present study have caused any change in the fibre length, uniformity of length or fibre maturity.

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A NEW METHOD FOR THE ESTIMATION OF SILT AND CLAY IN SOILS

THE BUOYANCY TECHNQIUE*

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(With one text-figure)

THE hydrometer technique in the mechanical analysis of soils was first introduced by Bouyoucos [1927]. In this method the estimation of soil colloids is carried out by dispersing the soil and finding out the density of the soil suspension by means of a special hydrometer, after a definite interval of time. This method has, however, many defects as is apparent from the following statement of Keen [1928]: "Hence in physical terms, the hydrometer technique consists in measuring at an arbitrary time the average density of a layer of suspension several cm. in length, whose density is continually changing with depth and time. The statement that the method is 'essentially qualitative' is not a matter of opinion but of fact."

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Some of these objections have been overcome by Puri [1932] in a new type of hydrometer. Recently, Puri [1939] has described another instrument 'the chaino-hydrometer' which practically removes all the objections against the hydrometer technique. The only source of error that may creep in is that the density gradient around the hydrometer bulb in the sedimenting column may not be uniform. By extensive empirical investigations, Puri has shown that the error from this source is inappreciable in most cases.

The chaino-hydrometer is, however, difficult to construct and the stem of the hydrometer cannot be made quite thin as it has to support a frame carrying the chain. The buoyancy technique described in the present paper is a logical development of the chaino-hydrometer, and yields more accurate results. A few soils have been investigated and the results obtained have been compared with those given by the pipette method.

Experimental

The international A method was employed for dispersing the soils. The soil was treated in 100 gm. lots and a large stock of the suspension prepared to avoid errors in sampling.

It was found that the soil suspension, on ageing, developed compound particles which were not broken up by the simple process of inverting the jar containing the suspension repeatedly for one minute. It was found that a preliminary shaking for 5 min. on a mechanical shaker was highly helpful in giving reproducible results. Each suspension was given this treatment prior to the determination of silt and clay.

The buoyancy technique

A cylindrical glass bulb was suspended in a sedimenting column of the soil suspension so that the centre of buoyancy of the bulb was kept at 10 cm. below the surface of the sedimenting column. After an interval of 4 min. and 10 sec. (corresponding to 26°C.), the apparent loss in weight of the bulb was determined by using the new type of continuous reading balance devised by Venkatachala, Doss and Rao*. A diagrammatic sketch of the instrument is given in Fig. 1. A balance (sensitiveness 1 mg.) had hooks B and C attached to the underside of the two scale pans. The buoyancy bulb A was suspended from the hook B by means of a fine nichrome wire which passed through a hole in the stand on which the balance was mounted. From the other hook C, was similarly suspended a glass rod D, (of uniform diameter) dipping in xylene kept in a U-tube. A side tube E attached to one of the limbs of the U-tube carried a millimeter scale on

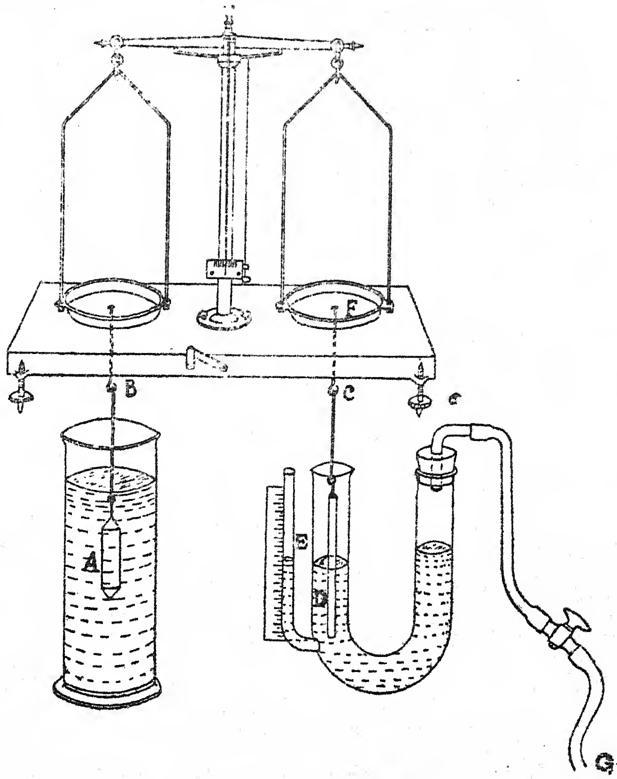

Fig. 1. Continuous reading balance (buoyancy principle)

which the level of xylene could be read. This device eliminated the use of weights smaller than 0·2 gm. in weighing. To counterpoise the buoyancy bulb, weights up to 0·2 gm. were placed in the scale pan F and the final adjustment was made by altering the level of xylene in the U-tube, by suction through G. Movements of the pointer of the balance were viewed through a lens attached to the balance. The diameter of the glass rod was such as to give an accuracy of 2 mg. which was quite adequate for present purposes. Weighings could be carried out very rapidly using this instrument.

Determination of the centre of buoyancy

The following method was adopted to find out approximately the centre of buoyancy. The buoyancy bulb was completely immersed in water kept in a narrow measuring jar and the volume of water displaced was noticed (V_2-V_1 c.c.). The bulb was then raised until the level came up to $\frac{V_2+V_1}{2} - \frac{2\pi R\gamma}{\rho g}$, where R is the radius of the cylinder, γ is the surface tension of water, ρ is the density of water and g is the acceleration due to gravity. The position of the meniscus was noted

* Unpublished

($l_1$cm.) by means of a scale. Water was then removed from the jar by suction until the water surface just touched the bulb. The new position of the meniscus was noticed ($l_2$cm.). The centre of buoyancy was l_2-l_1 cm.—above the tip of the bulb. This approximate method was adequate for most purposes.

To determine accurately the centre of buoyancy, the bulb A was counterpoised and the weight W_1 noted. The pans were then supported on wooden wedges so as to maintain the pointer at zero. A wide jar H containing distilled water (kept on a rising table stand), was placed under the bulb and adjusted till the bulb was completely immersed. The pan supports were then removed and the bulb again counterpoised (weight W_2). A weight equal to $\frac{W_1 - W_2}{2} + \frac{2\pi R\gamma}{g}$ was then added on to the right hand pan. The jar was then lowered until there was equilibrium. The surface of water in the jar would now be at the centre of buoyancy of the bulb. The distance between this surface of water and the bottom tip of the bulb A was measured by means of a cathetometer. A millimetre scale can be used in place of the cathetometer and is quite sufficient for most purposes.

The results obtained by the graphical method of Puri [1939] and the methods herein described have been in close agreement. Both the new methods described above are simple, and quick. They can, moreover, be used with a bulb which is not symmetrical about the vertical axis while such symmetry is essential for the graphical method.

The silt and clay contents have been calculated using the formula :

$$\text{Wt. of soil (silt or clay) in gm. per 100 c.c. of suspension} = \frac{\text{loss of wt. under soil suspension} - \text{loss of wt. under dispersion medium}}{\text{loss of wt. under water} \times 0{\cdot}006269} \times \text{Density of water}$$

To find out the amount of clay, the buoyancy was determined after 7 hr. of sedimentation at 26°C. at a depth of 10 cm. Four soils were examined for their silt and clay contents by (*a*) the pipette method and (*b*) the buoyancy technique. The results are given in Tables I and II.

TABLE I

Silt+Clay in 100 gm. of soil

Pipette method			Buoyancy technique							
			Bulb 1				Bulb 2		Bulb 3	
No. of the soil	Average of five determinations	Average error	Average of five determinations—Depth 10 cm.	Average error	Average of five determinations—Depth 12·5 cm.	Average error	Average of five determinations—Depth 10 cm.	Average error	Average of five determinations—Depth 10 cm.	Average error
1	31·8	0·6	32·7	0·05	32·9	0·05	33·3	0·01	30·7	0·01
2	25·2	0·1*	27·2	0·07	25·4	0·02	..	..	25·4	0·03
3	49·3	0·7	49·3	0·09	49·9	0·08	49·1	0·03	52·3	0·05
4	29·1	0·6	31·7	0·05	29·1	0·10	..	..	29·1	0·05

*This low error is unusual

Soils 1 and 2 were 'red soils' from the Government Agricultural Farm, Hebbal, (Bangalore)
Soils 3 and 4 were 'black cotton' soils from the Government Experimental Farm, Hiriyur (Mysore State)

TABLE II

Amount of clay in 100 gm. of soil

No. of the soil	Pipette method	Buoyancy method
1	28·4	30·7
2	22·7	23·8
3	0·75	1·1
4	1·44	2·5

DISCUSSION

An examination of Table I shows that the average error in the buoyancy measurements by the present technique is hardly 0·1 per cent in the value of the percentage of silt and clay. The pipette method, however, has an average error of 0·7 per cent. The differences in values obtained, when bulbs of different sizes are employed, are presumably due to non-uniformity in density gradients existing in the suspensions examined. These differences are rather high but are still

of the same order as the errors in sampling. The buoyancy technique can therefore be conveniently employed for mechanical analysis, in place of the rather laborious pipette method especially when quickness and moderate accuracy are aimed at. The buoyancy method is more accurate than the hydrometer technique. Theoretically, the former technique corresponds to a chaino-hydrometer with an exceedingly fine stem. The buoyancy bulbs are easily constructed and the experimental outfit can be readily assembled.

Use of the Buoyancy technique to obtain complete summation curves

It is of interest to consider whether the buoyancy bulb can be employed to get the complete summation curve. A detailed theoretical consideration shows that a short cylinder with a flat bottom suspended in a suspension is exactly equivalent to a sedimentation pan placed at the level of the bottom of the cylinder, when one takes into account the combined effect of settling of the particles (*a*) around the cylinder which would affect the buoyancy and (*b*) on the top of the cylinder which would affect the weight of the cylinder. The sedimentation curve can, therefore, be obtained as in the sedimentation balance. But, the buoyancy bulb has no special advantage over the sedimentation balance.

A precision buoyancy technique

It is of interest to consider the best conditions under which the buoyancy technique would yield correct results. Let us consider a cylinder placed in a liquid column of varying density. It is well known that the buoyancy suffered by the cylinder is in no way dependent on the density of fluid above the top of the bulb or below the bottom of the bulb. It is entirely determined by the density of the liquid surrounding the bulb. On the basis of this idea, it is easy to see that the ideal conditions for the buoyancy technique are the following :

A flat cylinder is immersed into the sedimenting column at the appropriate time so that the centre of the cylindrical bulb is at the level at which the density of the suspension is to be measured. The suspension is to be contained in the jar which is just 0·5 cm. to 1 cm. wider than the diameter of the cylindrical bulb. The introduction of the cylinder stirs up the upper portions of the sedimenting column but this does not matter in the least, as already pointed out. When the centre of the bulb occupies the proper level, the liquid surrounding the bulb is contributed by a thin layer around the level corresponding to the centre of buoyancy of the bulb. Thus we get the average density of a thin layer of the suspension at the appropriate depth. This is what is aimed at by the pipette technique but is rarely achieved due to stream line effects. In this respect this modified buoyancy technique presumably surpasses even the pipette technique in precision.

There is no difficulty experimental or theoretical in adopting this technique for the determination of clay. In the determination of silt and clay, however, the particles settling over the cylinder may interfere. This difficulty can be overcome by introducing the buoyancy bulbs just at the appropriate time and taking a few measurements at intervals of 2 min. and extrapolating the value for zero time (i.e. the time of introduction of the bulb).

If a high degree of precision is not aimed at, a narrow cylindrical bulb in a wide jar is more convenient than a flat cylinder in a narrow jar.

Correct conditions for the determination of silt+clay and clay using Buoyoucos' hydrometer

An examination of the Bouyoucos' hydrometer has revealed to us that the markings on the hydrometer, though empirical as claimed by the maker, correspond exactly to the densities of the soil suspensions having the corresponding concentrations of soil. But in order that the Buoyoucos' hydrometer may be employed for the determinations of silt and clay the following procedure is to be adopted.

Let the position of the centre of buoyancy of the hydrometer be found out by the method described in this paper. Let the vertical distance between the centre of buoyancy and the zero of the hydrometer be l_1 cm. If the hydrometer is lowered into the jar (supplied with it) containing water until it is immersed up to the centre of buoyancy let the displacement of the level of the water be l_2 cm. If t_1 minutes is the time corresponding to a height of 10 cm. for the determination of clay (or silt plus clay), calculate the value of t_2 by the equation

$$t_2 = \frac{l_1+l_2}{10} \times t_1.$$

The suspension is now put into the jar up to the mark. Sedimentation is allowed to occur after shaking the suspension. At the end of (t_2-1) minutes the hydrometer is introduced into the suspension, so that it floats freely. The suspension is sucked off from the top into a wash bottle by means of a filter pump until the zero of the hydrometer is at the same level as the mark on the jar (i.e. the former level of the suspension). The hydrometer reading is noted at t_2 minutes. It gives directly the number of grams of soil per litre of the suspension. A correction may be applied for the value got by putting the hydrometer in the medium in which the soil is dispersed.

The timings and procedure given by Bouyoucos are theoretically not justifiable. The above procedure removes most of the errors of the Bouyoucos' hydrometer technique. The only error which remains over is that the position of the centre of buoyancy depends upon the extent to which the hydrometer gets immersed while floating in the suspension. The error introduced on this score is, however, within the limits of accuracy of the instrument.

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SOME FUNGI FROM ASSAM, I

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(Received for publication on 4 December 1943)

In the course of the past two years the writer was able to collect a few parasitic fungi occurring both on cultivated and wild plants in some parts of Assam. Even though fungi were collected in the Khasi Hills by Hooker and Thompson early in the nineteenth century and by Butler and Subramaniam between the years 1910-15, a systematic collection of fungi in Assam has yet to be made. The nature of the country with its dense forests and heavy rainfall indicates, however, that there may be many species as yet unrecorded for India and new to science. A beginning has therefore been made in collecting and identifying them as opportunities permit. The collections listed below were identified in the *Herb. Crypt. Ind. Orient.* of the Imperial Agricultural Research Institute, New Delhi.

I. Phycomycetes

Oomycetes

Cystopus candidus (Pers.) Lév.

On the leaves and stems of *Brassica Napus* L.; Habiganj. Collected on 27 January 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Phytophthora Arecae (Coleman) Pethybridge

On the leaves, fruits and peduncles of *Areca Catechu* L.; Karimganj, Tajpur. Collected on 7 December 1941 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

P. Colocasiae Raciborski

On the leaves, petioles, flowers and corms of, *Colocasia antiquorum* Schott.; Baniachong, Inathganj, Sylhet. Collected on 7 October 1941 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

P. infestans de Bary

On all parts of *Solanum tuberosum* L.; Khasi Hills, Biswanath. Collected on 26 February, 1943 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

P. parasitica Dastur

On the leaves and stems of *Piper Betle* L Throughout the district of Sylhet. Collected on 7 May, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Zygomycetes

Rhizopus Artocarpi Raciborski

On the young immature fruits of *Artocarpus integrifolia* L.; throughout the province. Collected on 14 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

II. Ascomycetes

Hemiascomycetes

Taphrina deformans (Berk.) Tul.

On the leaves of *Prunus persica* Benth. & Hooker f.; Shillong. Collected on 7 August, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

T. maculans Butler

On the leaves of *Curcuma longa* L.; Sylhet, Maulvibazar. Collected on 10 November, 1941 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Pyrenomycetes

Erysiphe Polygoni DC.

On the leaves of *Pisum sativum* L.; Sylhet. Collected on 17 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Meliola palmicola Wint.

On the leaves of *Phoenix sylvestris* Roxb.; Jorhat, Sibsagar. Collected on 19 May, 1943 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Ustilaginoidea virens (Cke) Takahashi.

In the inflorescence of *Oryza sativa* L.; Karimganj, Habiganj, Inathganj, Jagatsi. Collected on 28 November, 1941 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

III. Basidiomycetes

Ustilaginales

Ustilago Cynodontis P. Henn.

In the inflorescence of *Cynodon Dactylon* Pers. Kulaura, Duttgram. Collected on 2 January, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

U. Hordei (Pers.) Lagerheim

In the ovaries of *Hordeum vulgare* L.; Dullabcherra, Jorhat. Collected on 2 March, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

U. nuda (Jensen) Rostrup

In the inflorescences of *Hordeaum vulgare* L.; Jorhat. Collected on 2 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

U. scitaminea Syd.

In the culms of *Saccharum officinarum* L. Bhanugach, Kamalpur. Collected on 25 March, 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

U. Coicis Bref.

In ovaries of Coix Lachryma-jobi L.; Shillong. Collected on 10 September, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

U. Tritici (Pers.) Rostrup

In ovaries of *Triticum vulgare* Host; Dullabcherra, Jorhat. Collected on 2 February, 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

U. Utriculosa (Nees) Tul.

In the ovaries of *Polygonum orientale* L. The fungus has not been previously recorded on this host in India and as far known, from elsewhere; Lakhipur. Binnakandi. Collected on 27 February, 1941 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Graphiola applanata Syd. & Butler

In living leaves of *Phoenix sylvestris* Roxb. Habiganj, Maulvibazar. Collected on 1 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Sphacelotheca Rottboelliae (Syd. & Butler) Mundkur

In spikes of *Rottboellia protensa* Hack. The fungus has not been previously recorded on this host; Habiganj. Collected on 7 March, 1943 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Cintractia Mundkuri Chowdhury n. sp.

Sori at the base of flower stalks, forming compact black roundish swellings, at first covered by a whitish false membrane, which soon flakes away exposing dark coloured spore masses. Spore masses amorphous, forming agglutinated more or less firm mass of spores. Spores spherical, yellowish brown, 11·6 to 15·8 μ (mean 13·4μ) with thick exospore and highly granular cell contents, giving the spores a reticulate appearance.

At the base of floral stalks of *Fimbristylis diphylla* Vahl.; Habiganj. 7 March, 1942. Collected by S. Chowdhury.

Type specimen deposited in the *Herb. Crypt. Ind. Orient.* New Delhi *Cintractia Mundkuri* Chowdhury sp. nov.

Sori ad basim florum inveniuntur, formantes alveolos densos, nigros et sub-rotundos, primum sub-albo falso membrano tectos, qui mox cadens spororum massas atras exponit. Haemassae sunt amosphàéet plus minusve agglutinatae. Spori rotundi, flavo-mauri coloris, 11·6—15·8 μ (med. 13 4 μ) cum exosporo crasso et valde granularibus cellulis composito, et faciens sporos reticulatos in apparentia.

Ad basim florum *Fimbristylis diphyllae* Vahl. Habiganj 7 Martii, 42 Leg. S. Chowdhury.

Specimen typicum depositum in *Herb. Crypt. Ind. Orient.* Nova Delhi.

Tilletia horrida Takahashi

In the grains of *Oryza sativa* L., throughout the province. Collected on 17 December, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Uredinales

Melampsora Lini (Pers.) Lev.

On the leaves and stems of *Linum usitatissimum* L.; Habiganj. Collected on 7 March, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Puccinia graminis Pers.

On the stems and leaves of *Triticum vulgare* Host; Dullabcherra. Collected on 10 March, 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

P. glumarum (Schm.) Erikss. & Henn.

On the leaves and culms of *Triticum vulgare* Host; Dullabcherra. Collected on 8 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

P. scirpi DC.

Uredo and teleuto stages on leaves of *Scirpus articulatus* L.; Kasba. Collected on 21 December, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Uromyces Fabae (Pers.) de Bary

On the leaves; stems and pods of *Pisum sativum* L.; Sylhet. Collected on 17 February, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

IV. Fungi Imperfecti

Hyphomycetes

Alternaria Brassicae (Berk.) Sacc.

On the leaves, stems and pods of *Brassica campestris* L. Habiganj, Karimganj. Collected on 8 January, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

A. solani (Ell & Mart.) Jones & Grout.

On the leaves of *Solanum tuberosum* L.; Sylhet, Somarai. Collected on 7 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet and in the *Herb. Crypt. Ind. Orient.*

Cercospora Calotropidis Ell. & Ev.

On the leaves of *Calotropis gigantea* Br.; Samshernagar. Collected on 17 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. Carthami Sundaraman & Ramkrishnan

On the leaves of *Carthamus tinctorius* L.;Hazipur, Manu. Collected on 4 March, 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. Concors (Casp.) Sacc.

On the leaves of *Solanum tuberosum* L.; Sylhet, Basudevsri. Collected on 18 January, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. cruenta Sacc.

On the leaves of *Phaseolus vulgaris* L.; Kalighat, Rajnagar. Collected on 19 January, 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. Hibisci Tracy & Earle

On the leaves of *Hibiscus sabdariffa* L.; Sylhet. Collected on 20 February, 1943 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. Occidentalis Cke.

On the leaves of *Cassia occidentalis* L.; Shaistaganj. Collected on 27 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. personata (Berk. & Curt.) Ell. & Ev.

On the leaves, stems and petioles of *Arachis hypogaea* L.; Sylhet. Collected on 2 July, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. Sesami Zimm.

On the leaves and stems of *Sesamum orientale* L.; Sylhet. Collected on 2 July, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Fusarium moniliforme Sheld.

On the roots and culms of *Oryza sativa* L.; Karimganj. Collected on 7 October, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Helminthosporium Oryzae Breda de Haan.

On the leaves of *Oryza sativa* L.; Sylhet, Inathganj. Collected on 25 June, 1942 and kept in the *Herb. Crypt. Ind. Orient.* and in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Piricularia Oryzae Cavara.

On the leaves of *Oryza sativa* L.; Akbarpur, Jorhat, Titabar. Collected on 7 August, 1941 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Sphaeropsidales and Melanconiales

Colletotrichum falcatum Went

On the leaves and culms of *Saccharum officinarum* L.; Sylhet, Silchar. Collected on 17 August, 1943 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. Gloeosporioides Penzig.

On *Citrus Aurantium* L.; Sylhet, Khasi Hills, North Cachar Hills. Collected on 18 February, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

C. graminicolum (Ces.) Wils.

On the leaves of *Andropogon Sorghum* Brot. Katakhal. Collected on 7 July, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Diplodia Corchori Syd.

On stems of *Corchorus capsularis* L. and *C. olitorius* L.; Habiganj, Agna. Collected on 17

September, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

Gloeosporium Musarum Cke & Massee

On fruits of *Musa paradisiaca* L.; Samshernagar, Kanaighat. Collected on 12 July, 1942 and kept in the Herbarium of the Plant Pathological Laboratory, Sylhet.

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ESTIMATION OF SUGARCANE TOP-BORER (*SCIRPOPHAGA NIVELLA* F.) INFESTATION

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THE extension of the area under sugarcane and the changes in the cultivation practices of this crop have brought the problem of its insect pests to the fore front. Sugarcane top-borer (*Scirpophaga nivella* F.) heads the list of these pests in India in general and the Punjab in particular. Therefore, in view of the losses inflicted by this pest on the sugarcane crop, the Entomologist, the Agronomist, and the Cane Breeder want to know (*i*) its relative abundance in different localities and extent of its damage during different years, and (*ii*) the comparative resistance of different varieties of sugarcane to it. In order to find this information it is essential to study the percentage of shoots attacked by the top-borer and to achieve this object the only method so far known is to count, separately over the whole field the entire nunber of healthy and infested shoots, and then to work out the extent of infestation therefrom. This is a very tedious, time-consuming, and costly task, particularly when the number of varieties and the areas under them are large.

The importance of a correct and a convenient method of finding the top-borer infestation can hardly be over-emphasized. Myers [1932] asserts that 'what we most clearly lack is a standard method of estimating infestation and determining damage'. The size of the sample and the number of replications should be such as to reduce the Standard Error of the data to a practical minimum: the number of canes to be counted should, consistent with efficiency, be as small as possible. The need for standardizing the technique for finding top-borer infestation is further emphasized by the fact that the spread of sugarcane top-borer does not follow any regular law of soil fertility or a topo-graphical curve. Investigations were, therefore, undertaken with Co 285 canes in order to find a suitable, convenient and, at the same time, correct method for estimating top-borer infestation in a given area. The results of these investigations are presented in this paper.

METHOD AND MATERIAL

A one-third acre field of sugarcane, Co 285, with normal stand was selected at the Sugarcane Research Station, Jullundur, and the counts were made in the field during November when the sugarcane top-borer infestation had touched the peak. The field was divided with ropes for the purpose of making the counts into 40 equal sub-plots which extended parallel to the width of the field. In each of these sub-plots all the canes were counted in separate sections of 50 canes each, and the number of top-borer affected canes in such sections was also recorded. Thus the infestation figures from 400 sections each with 50 canes were collected for statistical analysis. These figures are given in Table I.

The frequency of the number of sections which have different infestation percentages is given in Table II.

It is clear from Table II that the frequency diagram would be approximately a normal one. The statistics known as $g1$ and $g2$ were calculated to test the departure of the frequency curve from the normal. The values of these statistics were found to be—$0 \cdot 202 \pm 0 \cdot 122$ and $0 \cdot 282 \pm 0 \cdot 243$ respectively. These values indicate that the frequency curve possesses a negative skewness and is a peaked one. The values of $g1$ and $g2$, though greater than their Standard Errors, do not bring out or point to a significant deviation from normality. It is, therefore, apparent that the present technique evolved for the estimation of sugarcane top-borer infestation can be recommended to the research workers

TABLE I

Exact number of top-borer affected canes in each section of 50 canes

22	30	20	22	22	18	25	27	14	33	27	21	19	19	25	13	19	21	20	25	25	17	15	14	6	11	5	12	18	15	13	21	16	12	10	8	14	10	24	15
21	35	21	25	19	32	34	33	38	40	37	32	31	24	22	27	29	29	26	24	35	28	25	28	31	19	14	36	23	18	9	20	30	24	12	29	15	23	21	23
23	35	32	34	32	32	27	35	22	32	39	33	24	29	23	37	25	28	24	29	34	24	24	29	28	26	28	28	35	29	18	18	26	24	24	28	32	26	19	22
21	34	33	33	31	33	32	40	43	25	28	31	36	35	32	37	46	41	28	24	29	22	23	37	34	30	34	33	22	22	25	30	35	21	24	21	30	29	31	26
26	40	32	34	35	33	34	33	33	34	41	34	31	41	33	34	42	31	34	29	33	31	25	22	27	33	23	25	17	30	29	37	31	28	14	32	35	19	23	25
26	35	31	31	26	27	21	31	32	30	24	25	45	41	36	30	29	39	26	33	41	29	30	33	48	18	22	24	30	27	31	29	28	26	20	43	14	26	28	29
25	25	26	32	33	31	40	41	39	32	29	25	27	47	30	34	38	28	32	24	31	42	35	21	20	19	20	20	29	30	21	28	26	22	25	38	29	32	31	34
34	21	48	30	36	23	29	41	33	40	27	25	22	40	44	28	35	29	31	32	24	30	35	8	32	24	36	24	22	31	37	26	28	22	29	17	30	26	31	38
21	34	22	25	24	27	32	38	29	30	24	21	25	26	35	29	19	31	28	37	20	38	34	21	33	29	27	23	39	40	36	27	24	31	31	23	27	32	26	26
22	30	16	29	31	34	24	30	35	40	32	32	19	36	39	30	31	28	19	30	19	28	34	24	34	23	30	31	28	31	31	28	37	29	27	22	25	31	33	33

TABLE II

Spread of infestation in 400 sections

Infestation percentage	Number of sections which have this infestation percentage	Infestation percentage	Number of sections which have this infestation percentage
10	1	56	22
12	1	58	26
14	0	60	21
16	2	62	28
18	1	64	24
20	2	66	20
22	1	68	17
24	3	70	14
26	2	72	7
28	6	74	9
30	4	76	6
32	2	78	5
34	3	80	8
36	6	82	7
38	13	84	2
40	8	86	2
42	17	88	1
44	18	90	1
46	12	92	1
48	21	94	1
50	21	96	2
52	18		
54	14	Total .	400

engaged on this problem. The lines of work detailed in the present paper should arouse similar interest amongst other workers on sugarcane entomology in India.

The infestation of 12 sample sizes, i.e., 50 100, 200, 250, 400, 500, 800, 1,000, 1,250, 2,000 2,500 and 5000 canes taken as representative samples from a total population of 20,000 canes, were combined in all possible ways for the purpose of finding out a suitable size and shape of the sample and the number of times for which such sample should be repeated. There were thus obtained 21 different combinations and these combinations account for all the different sizes and shapes of the sample.

Experimental results

The figures of infestation percentage in the whole field of 400 sections, grouped according to the nature of the samples were analysed statistically by the following two methods, (*i*) the sum of squares due to columns and rows was not eliminated, and (*ii*) the effect of columns and rows was eliminated with a view to obtain (*a*) an average trend of the size of the sample and (*b*) figures which are neither too low nor too high.

Table III

Serial No.	Nature of the sample	No. of canes in the sample	No. of replications	Mean percentage of attack per sample	Standard deviation	Standard error on per cane basis	Co-efficient of variation	Standard error of Co-efficient of variation	Relative precision corrected for number of replications
	(Rows × Cols.)								
1	1×1 . .	50	400	56·1	14·622	2·068	26·064	0·9215	100
2	1×2 . .	100	200	56·1	11·945	1·1945	21·292	1·0646	75
3	2×1 . .	100	200	56·1	11·796	1·1796	21·027	1·0513	77
4	1×4 . .	200	100	56·1	10·324	0·7300	18·403	1·3014	50
5	2×2 . .	200	100	56·1	9·800	0·6930	17·468	1·2139	55
6	5×1 . .	250	80	56·1	9·970	0·6306	17·789	1·4063	43
7	1×5 . .	250	80	56·1	8·293	0·5245	14·782	1·1686	62
8	1×8 . .	400	50	56·1	9·219	0·4610	16·433	1·6433	31
9	2×4 . .	400	50	56·1	8·808	0·4404	15·686	1·5686	34
10	5×2 . .	500	40	56·1	8·930	0·3994	15·919	1·7798	26
11	2×5 . .	500	40	56·1	8·595	0·3844	15·321	1·7467	28
12	1×10 . .	500	40	56·1	6·538	0·2924	11·654	1·3029	49
13	2×8 . .	800	25	56·1	8·078	0·2856	14·399	2·0363	20
14	5×4 . .	1000	20	56·1	8·675	0·2743	15·454	2·4439	14
15	2×10 . .	1000	20	56·1	7·937	0·2510	14·148	2·2372	16
16	1×20 . .	1000	20	56·1	5·836	0·1845	10·403	1·6450	29
17	5×5 . .	1250	16	56·1	5·844	0·1653	10·417	1·8415	24
18	5×8 . .	2000	10	56·1	7·682	0·1718	13·684	3·0598	8
19	2×20 . .	2000	10	56·1	5·439	0·1216	9·695	2·1679	16
20	5×10 . .	2500	8	56·1	5·989	0·1198	10·675	2·6687	11
21	5×20 .	5000	4	56·1	5·807	0·0821	10·351	3·6600	5

The values of the Standard Deviation, Standard Error, the Co-efficient of Variation, Standard Error of Variance and the Relative Precision for all the 21 combinations both before and after eliminating the effects of columns and rows are given in Table III and Table IV respectively.

In Tables V and VI, the samples containing the same number of canes but with different shapes are grouped together and the average Standard Deviation, Standard Error, the Co-efficient of Variation and the Standard Error of Coefficient of Variation for each shape are worked out. It is seen from Table V that the Standard Deviation, Standard Error, and the Coefficient of Variation fall rapidly in value from a sample of 50 canes to one having 200 canes but later on the fall is gradual. The reduction in the value of these statistics from samples of 500 canes to those having 800 canes is small and the difference of these values for samples of 1000 to 2000 canes

TABTE IV

Serial No.	Nature of the sample	No. of canes in the sample	No. of replications	Mean percentage of attack per sample	Standard deviation after removing the effect of rows and columns	Standard error on per cane basis	Co-efficient of variation after removing the effect of rows and columns	Standard error of coefficient of variation	Relative precision corrected for number of replications
	(Rows × Cols.)								
1	1×1 . .	50	400	56·1	12·349	1·746	22·0107	0·7782	100
2	1×2 . .	100	200	56·1	8·809	0·8809	15·7023	0·7851	71
3	2×1 . .	100	200	56·1	9·889	0·9889	17·6112	0·8806	80
4	1×4 . .	200	100	56·1	6·805	0·4812	12·1354	0·8581	55
5	2×2 . .	200	100	56·1	6·697	0·4736	11·9376	0.8441	54
6	5×1 . .	250	80	56·1	7·307	0·4621	13·0251	1·0298	59
7	1×5 . .	250	80	56·1	5·775	0·3653	10·2940	0·8139	47
8	1×8 . .	400	50	56·1	4·772	0·2386	8·5062	0·8506	39
9	2×4 . .	400	50	56 1	5·283	0·2642	9·4171	0·9417	43
10	5×2 . .	500	40	56·1	4·461	0·1995	7·9518	0·8890	36
11	2×5 . .	500	40	56·1	4·555	0·2037	8·1196	0·9078	37
12	1×10 . .	500	40	56·1	4·227	0·1890	7·5240	0·8412	34
13	2×8 . .	800	25	56·1	3·857	0·1364	6·8752	0·9723	31
14	5×4 . .	1000	20	56·1	4·211	0·1332	7·5062	1·1853	34
15	2×10 . .	1000	20	56·1	3·845	0·1216	6·8538	1·0837	31
16	1×20 . .	1000	20	56·1	4·211	0·1332	7·5062	1·1853	34
17	5×5 . .	1250	16	56·1	3·240	0·0916	5·7575	1·0178	26
18	5×8 . .	2000	10	56·1	3·920	0·0877	6·9875	1·5625	32
19	2×20 . .	2000	10	56·1	3·930	0·0878	7·0053	1·5664	32
20	5×10 . .	2500	8	56·1	3·142	0·0628	5·6007	1·4002	25
21	5×20 . .	5000	4	56·1	2·900	0·0410	5·1693	1·8276	23

In order to obtain the suitable size and shape of the samples the data in Tables III and IV were arranged in the form of Tables V and VI respectively

is again very little and it may therefore be inferred that the Standard Error and the Coefficient of Variation do not fall appreciably if the size of the sample is increased from 1000 to 2000 canes. Table VI also leads to similar inferences. Thus it can be safely concluded that from the point of view of precision there appears to be very little advantage in increasing the size of the sample beyond 500 canes.

Another interesting feature apparent from Tables V and VI is that for the same number of canes in the sample, there is a reduction in the Standard Error if the shape of the sample chosen be a long and narrow one. A few discrepancies here and there, however, do not upset the general finding. The length of the patch from which the required number of canes is to be counted should be much greater than its width. A similar finding was obtained by Panse [1941] while dealing with the efficiency of different plot sizes. According to him the Standard Error decreased considerably if the plot was long and narrow.

TABLE V

No. of canes	No. of replications	Shape of the sample	Standard deviation	Standard error	Co-efficient of variation	Standard error of coefficient of variation
50	400	1 : 1	14·622	2·068	26·064	0·9215
100	200	1 : 2	11·945	1·1945	21·292	1·0646
100	200	2 : 1	11·796	1·1796	21·027	1·0513
Average			11·870	1·187	21·160	
200	100	1 : 4	10·324	0·7300	18·403	1·3014
200	100	1 : 1	9·800	0·6930	17·468	1·2139
Average			10·062	0·7115	17·935	
250	80	5 : 1	9·970	0·6306	17·789	1·4063
250	80	1 : 5	8·293	0·5245	14·782	1·1686
Avreage			9·132	0·5776	16·286	
400	50	1 : 8	9·219	0·4610	16·433	1·6433
400	50	1 : 2	8·808	0·4404	15·686	1·5686
Average			9·013	0·4507	16·060	
500	40	1 : 2·5	8·930	0·3994	15·919	1·7798
500	40	2·5 : 1	8·595	0·3844	15·321	1·7467
500	40	1 : 10	6·538	0·2924	11·654	1·3029
Average			8·21	0·3587	14·298	
800	25	1 : 4	8·078	0·2856	14·399	2·0363
1000	20	5 : 4	8·675	0·2743	15·454	2·4439
1000	20	1 : 5	7·937	0·2510	14·148	2·2372
1000	20	1 : 20	5·836	0·1845	10·403	1·6450
Average			7·483	0·2366	13·335	
1250	16	1 : 1	5·844	0·1653	10·417	1·8415
2000	10	1 : 1·6	7·682	0·1718	13·684	3·0598
2000	10	1 : 10	5·439	0·1216	9·695	2·1679
Average			6·560	0·1467	11·689	
2500	8	1 : 2	5·989	0·1198	10·675	2·6687
5000	4	1 : 4	5·807	0·0821	10·351	3·6600

The sample of 500 canes having different shapes, viz. 1 : 2·5 and 1 : 10 as the nature of the sample were studied. Both the Tables V and VI indicate a fall in the values of the Standard Deviation, Standard Error and the Coefficient of Variation in the sample with 1 : 10 as its shape. Thus we arrive at the conclusion that 500 canes with 1 : 10 as the ratio in the breadth and the length of the patch from which this number of canes is counted is probably the best among the samples considered in the present investigations.

It is clear from Tables V and VI that samples having 500, 800 and 1000 canes differ very little in the values of the Standard Deviation, Standard Error and the Coefficient of Variation. A further study about the number of replications of such samples will also help to determine the requisite size of the sample. The number of samples required to give Standard Error of 5 per cent was calculated by dividing the Coefficient of Variation of the sample by $\sqrt{n}$.

TABLE VI

No. of canes	No. of replications	Shape of the sample	Standard deviation	Standard error	Co-efficient of variation	Standard error of coefficient of variation
50	400	1 : 1	12·349	1·746	22·0107	0·7782
100	200	1 : 2	8·809	0·8809	15·7023	0·7851
100	200	2 : 1	9·889	0·9889	17·6112	0·8806
Average			9·349	0·9349	16·6568	
200	100	1 : 4	6·805	0·4812	12·1354	0·8581
200	100	1 : 1	6·697	0·4736	11·9376	0·8441
Average			6·751	0·4774	12·0365	
250	80	5 : 1	7·307	0·4621	13·0251	1·0298
250	80	1 : 5	5·775	0·3653	10·2940	0·8139
Average			6·541	0·4137	11·6596	
400	50	1 : 8	4·772	0·1236	8·5062	0·8506
400	50	1 : 2	5·283	0·2642	9·4171	0·9417
Average			5·028	0·2514	8·9616	
500	40	1 : 2·5	4·555	0·2037	8·1196	0·9070
500	40	2·5 : 1	4·461	0·1995	7·9518	0·8898
500	40	1 : 10	4·227	0·1890	7·5240	0·8412
Average			4·414	0·1974	7·8651	
800	25	1 : 4	3·857	0·1364	6·8752	0·9723
1000	20	5 : 4	4·211	0·1332	7·5062	1·1853
1000	20	1 : 5	3·845	0·1216	6·8538	1·0837
1000	20	1 : 20	4·211	0·1332	7·5062	1·1853
Average			4·890	0·1293	7·2877	
1250	16	1 : 1	3·240	0·0916	5·7575	1·0178
2000	10	1 : 1·6	3·920	0·0877	6·9875	1·5625
2000	10	1 : 10	3·930	0·0878	7·0053	1·5664
Average			3·925	0·0878	6·9964	
2500	8	1 : 2	3·142	0·0628	5·6007	1·4002
5000	4	1: 4	2·900	0·0410	5·1693	1·8276

TABLE VII

Number of samples	Without removing the effect of columns and rows						After removing the effect of columns and rows					
	Size of the sample						Size of the sample					
	500 canes		800 canes	1000 canes			500 canes		800 canes	1000 canes		
	Shape of the sample		Shape of the sample	Shape of the sample			Shape of the sample		Shape of the sample	Shape of the sample		
	1 : 2·5	1 : 10	1 : 4	1 : 1·25	1 : 5	1 : 20	1 : 25	1 : 10	1 : 4	1 : 1·25	1 : 5	1 : 20
1	15·919	11·654	14·399	15·454	14·148	10·403	8·119	7·524	6·875	7·5062	6·853	7·5
2	11·37	8·241	10·285	11·04	10·000	7·359	5·792	5·302	4·904	5·290	4·888	5·29
3	9·36	6·729	8·470	9·09	8·140	6·000	4·700	4·360	4·000	4·350	4·000	4·35
4	7·959	5·827	7·195	7·727	7·074	5·201	4·059	3·762		3·753		3·753
5	7·23	5·212	6·545	7·02	6·335	4·673						
6	6·459	4·758	5·856	6·31	5·781	4·246						
7	6·071		5·333	5·85	5·351							
8	5·685		5·106	5·51	5·017							
9	5·306		4·799	5·151	4·716							
10												

For determining the number of replications of samples of three different sizes, viz. 500, 800 and 1000 canes, required to give accurate estimates, the data are arranged in Table VII.

Considering the variance without removing the effect of rows and columns, we find that if the size of the sample is to be 500 canes with shape 1 : 10 and 1 : 2·5 we would be required to take 6 and 9 replications respectively so as to make the sampling efficient enough to reduce the Standard Error to 5 per cent or lower. This further stresses the desirability of having a long and narrow patch for taking observations to record infestation percentage. Seven replications of the sample having 800 canes are needed and for a sample of 1000 canes, the number of replications required are 9, 8 and 5 for 5 : 4, 1 : 5 and 1 : 20 shapes respectively.

A similar study of the data after removing the effect of columns and rows reveals that 3 replications of the sample having 500 canes with shape 1 : 2·5 and 2 replications of the same sample with shape 1 : 10 reduce the Standard Error to about 5 per cent : two replications of the sample having 800 canes and shape 1 : 4 are necessary and for 1000 canes sample 2 to 3 replications are required.

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SUMMARY

Sugarcane top-borer (*Scirpophaga nivella* F.) is a serious pest of sugarcane in the Punjab and it is often required to accurately determine the extent of its infestation. The present paper presents the results of an Ento-Statistical investigation conducted with a view to find out the most suitable, efficient, and convenient size of the sample which would yield reliable information about the incidence of this pest. The infestation percentage figures in samples of various sizes and shapes have been examined statistically and the limits of accuracy have been determined. For ordinary routine work, a sample consisting of 500 canes has been shown to give quite accurate results. There appears to be very little advantage in precision if the size of the sample is increased beyond 500 canes. The precision is increased by taking long and narrow strips of the sugarcane crop for counting purposes. In special cases when greater efficiency is needed 3 to 6 replications of the sample consisting of 500 canes from strips with 1 : 10 and 1 : 2·5 as the ratios in their breadth and length respectively should be taken.

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A PRELIMINARY INVESTIGATION INTO THE INFLUENCE OF THE FUNDAMENTAL DIMENSIONS OF A PLOUGH ON DRAW-BAR-PULL, DEPTH AND RESISTANCE PER UNIT AREA

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(With two text-figures)

Introduction

The fundamental dimensions of an Indian plough are the length of the wedge (L), the angle between the beam and the wedge (θ_p), the face angle of the wedge (θ) (i.e. the angle between the two edges of the wedge) and the weight (W). These are independent of one another and can be adjusted in any manner according to requirements, subject to some limitations.

It can be seen from the following discussions that the angle between the beam and the wedge cannot be more than a particular value if the plough is to work smoothly. In the case of Indian ploughs the line of draw-bar-pull either coincides or makes a small angle with the beam. The functions of a plough are to cut and to crush the soil. It does cutting while penetrating the soil during which it will have to overcome a certain amount of resisting force which is represented by F in Fig. 1. It

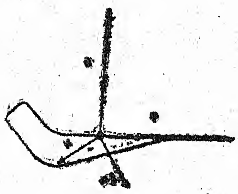

Fig. 1

crushes the soil during its forward push by the animals when it has to overcome a certain amount of complex foces in the soil, the resultant of which will act nearlry at about right angles to the wedge and is represented by N in Fig. 1. The force which is equivalent to frictional resistance against the motion of the plough is represented by H. The directions of these forces are indicated by arrows. Assuming the cutting and crushing forces to be equal, in view of the gravitational force of the weihgt acting on the plough, the actual force in Fig. 2. contributed by the draw-bar-pull in the direction of the wedge is less than F and hence the resultant (R) of this force and N will be inclined at an angle greater than 45° to the wedge. Compared with the other forces, H is small and the resultant of R and H which is represented by P in Fig. 2 will be inclined at about 45° to the

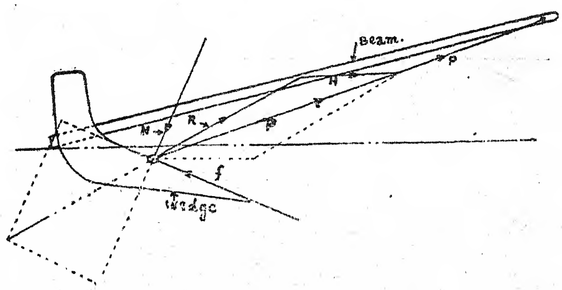

Fig. 2

wedge. This P is the draw-bar-pull and is recorded by dynamometer. We have already mentioned that the line of draw-bar-pull either coincides or makes a small angle with the beam. Hence the inclination of the beam with the wedge will be between 40° and 50° for smooth working. The weight of the plough should be adjusted in accordance with the strength required, but should not be increased unnecessarily in which case the average bullocks will find difficult to pull it. Similarly the face angle also has certain limitations. If the face angle is large, the resisting force against the penetration of the wedge is also large and the ploughing will not be deep enough under ordinary ploughing conditions. On the other hand, if the face angle is very small, the wedge will be too narrow and will penetrate to a greater depth which sometimes is not required. Besides this, the side pressure will be more and the draw-bar-pull will be large.

No work seems to have been done either in India or elsewhere regarding the influence of the fundamental dimensions of plough on draw-bar-pull, depth of ploughing and resistance per square inch of furrow opened. The available literature on the subject has been summarized below.

Contrary to the general opinion, Arthur Young [Keen, 1931] found that the draw-bar-pull was not affected by the weight of the plough to any appreciable extent. The main resistance was that offered by cohesion of the soil and could only be kept to a minimum by the proper design of

mould-board. Hadley [Keen, 1931] showed that the draught varied with the depth of ploughing and the gross draw-bar-pull appeared to be largely due to the frictional resistance between the sole and land side of the plough and not due to the mould-board. He confirmed Young's observation regarding the effect of weight of plough on the draw-bar-pull. White [1918] working at Illinios, America, attempted to work out the mathematical equations of surfaces of mould-boards of the most important historical ploughs. He also gave methods to generate plough bottoms for various soil conditions. Davies' at Rothamsted, studied the effect of the depth and width of the furrows on draw-bar-pull and found a linear relation existing between them. Keen and Haines [1925], at Rothamsted, showed that the relation between moisture and the draw-bar-pull is hyperbolic. Nichols [1931 ; 1932] at Albama, U. S. A., found a definite relation existing between friction, shear, resistance to the compression and the Atterberg consistency constants. In further dynamic studies of the soil, he established a relationship between friction and hardness of the metal of the plough share (or wedge) and colloidal contents of the soil. Godbole [1913] at Poona, in designing a new Deccan plough used the weight of the plough and the weight of the soil over the plough wedge in calculating the frictional resistance.

Attempts have been made in this paper to study the relation between the fundamental dimensions described above and draw-bar-pull, depth of the furrow and the resistance per square inch of furrow. Mathematical equations showing the relationship between the various factors have been obtained. It may be mentioned that in place of the plough angle, the angle between the horizontal and the wedge at the time of ploughing has been used in these equations, in order to eliminate the effect of the length of the beam and the height of bullocks. These equations enable us to calculate the draw-bar-pull, the depth and the resistance for ploughs of any dimensions for the same conditions for which the relation has been established. These calculated values can be used to judge the *relative merits* of ploughs of different dimensions. Therefore these equations are likely to be of more practical value than the equations connecting draw-bar-pull with depth and width of furrow as obtained by Davies. In the former case the approximate values of draw-bar-pull, depth and resistance can be known without actual ploughing, while in the other case the draw-bar-pull can be known after ploughing only.

Experiment

Seventeen Indian ploughs collected from different parts of India were worked in the same field with the same pair of bullocks by the same ploughman. The field used for this purpose was plot 3 E in Main Block of the Farm area, the soil of which is sandy loam. The plot was ploughed and left fallow for two months before the experiment. The draw-bar-pull was recorded by a self-recording dynamometer similar to that used by Keen [1931], excepting that there was no arrangement for the automatic motion of the paper and for pin pricks to indicate any point of the furrow on the chart. The draw-bar-pull charts were obtained in this case by rotating the paper drum with hand by a man who was moving along with the plough with the dynamometer hanging from his neck. Therefore, the relation between the motions of paper and plough and the draw-bar-pull at any point of the furrow could not be found from the chart. The average draw-bar-pull for the different furrows was calculated by computing the area included between the curve and the base line by means of a planimeter and dividing the area by the length of base line and multiplying the quotient with the constant of the dynamometer. The depth and width of the furrow were measured with the help of a wooden divider. This was placed inside the furrow with its arms touching the sides of furrow and a wooden scale was placed across the furrow touching the divider. Then with a second scale the distance between the arms of divider at the top of furrow and the height of the horizontal scale from the bottom of furrows were measured. The former is the width and the latter is the depth of the furrow. The resistance was calculated by using the draw-bar-pull and the area of the cross-section of the furrow opened. Table I summarizes the results of this experiment.

Results and discussions

The partial regression coefficient between the draw-bar-pull and the depth and width of furrows, the weight of the plough, the time taken to open 100 ft. furrow, the moisture and the angle which the wedge makes with the horizontal were not significant in any of the cases excepting depth. This shows that draw-bar-pull is likely to depend more on the depth of ploughing than on any other factor for the conditions of this experiment; but the depth, as will be seen from the investigations that follow, will depend on the weight of plough, the length of the wedge, the face angle of the wedge and the angle which the wedge makes with the horizontal at the time of ploughing.

The correlation coefficient between the draw-bar-pull and the depth was 0·9259 and the regression equation connecting the draw-bar-pull with depth and its analysis of variance are given below:

TABLE I*

Name of the plough	Weight of the plough in lb.	Length of the wedge in inches	Angle which wedge makes with horizontal	θ		Moisture per cent	Time to open 100 ft. furrow in seconds	Width of furrow in inches	Depth of the furrow		D. B. P. in lb.	Resistance per sqr. in.	
				Observed value	Cultivated value				Observed value	Calculated value		Observed value	Calculated value
1. Country plough Indore	56·9	30	21·2	10·2	25·8	8·28	43	9·66	10·66	9·01	416·0	8·08	6·33
2. Country plough Dohad	28·7	35	21·2	8·2	34·1	7·66	24	9·33	9·33	6·33	360·0	8·28	2·91
3. Country plough Coimbatore	37·4	34	18·2	12·4	32·0	8·64	35	11·00	9·00	7·02	358·0	6·82	3·74
4. Country plough Baroda	50·7	36	18·0	13·3	27·6	8·34	33	11·50	8·00	8·45	305·6	6·63	5·57
5. Local plough Karnal	51·6	28	23·0	31·7	27·4	8·40	29	12·00	8·20	8·48	295·0	6·00	5·46
6. Country plough Bareilly No. 2	25·0	32	23·1	6·8	35·4	9·69	42	8·66	7·16	5·91	226·0	7·30	2·42
7. Plough Dacca Farm	23·9	34	24·9	14·0	36·6	9·45	28	9·33	7·00	5·50	182·0	5·57	1·96
8. Country plough Aligarh	29·2	29	20·0	16·8	35·3	9·18	34	9·83	7·66	5·95	166·2	4·41	2·47
9. Wooden plough Berhampore	36·4	31	14·2	17·0	34·0	9·33	28	10·00	7·66	6·38	134·4	3·51	2·97
10. *Desi* plough Gorakhpore No. 3	23·5	27	23·0	23·2	36·7	9·50	30	9·00	6·00	5·48	134·0	4·51	1·94
11. Country plough Bankura	31·0	28	18·8	39·0	35·1	9·81	27	12·00	6·33	6·00	127·7	3·36	2·53
12. Country plough Rangpur	20·0	24	19·1	19·2	39·3	9·56	25	9·00	5·67	4·64	126·5	4·96	1·05
13. Wooden plough Gorakhpore	22·6	28	23·0	21·2	36·8	9·15	30	9·66	6·33	5·44	118·0	3·86	1·89
14. *Desi* plough Gorakhpore	22·0	28	19·0	21·2	38·0	9·25	31	10·66	7·00	5·07	108·6	3·58	1·54
15. Local plough Chotanagpur Daltonganj	30·2	31	16·9	24·0	35·3	8·78	25	10·83	6·00	5·94	85·1	2·62	2·44
16. L. P. Chotanagpur Purelia	25·1	29	23·2	20·0	35·8	8·36	28	9·83	6·20	5·77	65·9	2·16	2·25
17. Udayagiri Orissa	17·2	22	21·5	18·6	40·0	8·59	23	10·33	6·00	4·42	82·3	2·65	0·81

* The help rendered by Mr A. K. Kaul, Engineering Assistant, Imperial Agricultural Research Institute, in maintaining the dynamometer is gratefully acknowledged

$Y = 74\cdot90\ d - 358\cdot07$; where Y stands for draw-bar-pull in lb. and d for depth of the furrow in inches.

In this equation when $d = 0$, the draw-bar-pull is $-358\cdot07$ lb. The draw-bar-pull is zero when $d = 4\frac{3}{4}$ in. This was so because the plot had been ploughed once two months before the experiment and it appeared to be difficult to measure the draw-bar-pull at depths less than the above value in this field.

Analysis of variance for Y *expressed in terms of* d

Variance due to	D. F.	S. S.	M. S. S.	Ratio of variation
Linear regression	1	166081·1	166081·1	90·5
Residual error	15	27665·9	1844·4	

The above analysis shows that the draw-bar-pull depends mainly on the depth of the furrow opened. This measurement of the depth can be known only by actual trials. But if it is possible, to establish some relationship between the depth (d) and the weight (W), length (L), face angle of the wedge (θ) and the angle which the wedge makes with the horizontal at the time of ploughing (Φ), the depth can be calculated approximately when the values of W, L, θ and Φ are known. It may be emphasized here that the depth so calculated will hold good only for the particular soil on which the experiment was conducted. The partial regression equation between d, W, L, θ and Φ and its analysis of variance are as follows:

$$d = 3\cdot489 + 0\cdot0829\ W + 0\cdot0437\ L - 0\cdot0684\ \theta + 0\cdot0595\ \Phi$$

Analysis of variance for d *expressed in terms of* W, L, θ, *and* Φ

Variation due to	D. F.	S. S.	M. S. S.	Ratio of variance
Regression	4	21·949	5·487	8·6
Residual	12	7·657	0·683	

The above table shows that the partial regression equation can be used to express d in terms of the independent measurements of a plough subject to a variation of about 11 per cent. It also shows that depth d increases as W, L and Φ increase but decreases as θ increases.

Since d is dependent on W, L, θ and Φ and Y is dependent on d, by combining the above two equations we have the following equation in which Y is expressed in terms of W, L, θ and Φ :—

$$Y = 6\cdot21\ W + 3\cdot27\ L + 4\cdot46\Phi - 5\cdot12\theta - 96\cdot74.$$

This equation enables us to calculate the draw-bar-pull directly with the knowledge of W, L, θ and Φ.

So far we have discussed the relationship between the fundamental dimensions of plough and draw-bar-pull and depth of ploughing. But to judge a plough completely, we must know the draw-bar-pull, the depth and the resistance (R) per unit area of the cross-section ploughed. Therefore we shall now examine the relation, if any, between resistance per square inch and other factors. The correlation coefficient between R and d and R and θ were $0\cdot791$ and $-0\cdot600$ respectively. As the above correlations are not so high as that between draw-bar-pull and depth, a second degree equation involving R, θ and d was fitted to the data. The equation and its analysis of variance are given below:

$$R = 24\cdot21 - 1\cdot063\ \theta + 0\cdot014\ \theta^2 + 0\cdot0715\ \theta\ d - 3\cdot010d + 0\cdot1616d^2.$$

Analysis of variance for R *expressed in terms of* θ *and* d

Variance due to	D. F.	S. S.	M. S. S.	Ratio of variance
Second degree equation	5	50·99	10·20	11·1
Residual error	11	10·16	0·92	

The analysis of variance shows that R can be estimated subject to a variation of about 19 per cent, if θ and d are known. If d is replaced in terms of W, L, θ and Φ we obtain an equation involving R, W, L, θ and Φ and this equation enables us to discuss how the resistance varies with the changes in W, L, θ and Φ. Using the partial regression equation between d, W, L, θ and Φ; R and d we get

$$R = 15\cdot68 - 0\cdot1561\ W - 0\cdot0822\ L - 0\cdot6848\ \theta - 0\cdot1120\ \Phi + 0\cdot0012\ W\ L + 0\cdot0041\ W\ \theta + 0\cdot0016\ W\ \Phi + 0\cdot0021\ L\ \theta + 0\cdot0008\ L\ \Phi + 0\cdot0030\ \theta\ \Phi + 0\cdot0011\ W^2 + 0\cdot0003\ L^2 + 0\cdot0063\ \theta^2 + 0.0006\ \Phi^2.$$

The coefficients of W^2, L^2, θ^2 and Φ^2 are all positive. Hence it follows that R will have a minimum value for certain values of W, L, θ and Φ. The equations which give the minimum values are :

$$\frac{dR}{dW} = -0\cdot156 + 0\cdot0012\ L + 0\cdot0041\ \theta + 0\cdot0016\ \Phi + 0\cdot0022\ W.$$

$$\frac{dR}{dL} = -0\cdot082 + 0\cdot0012\ W + 0\cdot0021\theta + 0\cdot0008\Phi + 0\cdot0006L$$

$$\frac{dR}{d\theta} = -0\cdot685 + 0\cdot0041W + 0\cdot0021\ L + 0\cdot0030\Phi + 0\cdot0126\theta$$

$$\frac{dR}{d\Phi} = -0\cdot112 + 0\cdot0016\ W + 0\cdot0008\ L + 0\cdot0030\theta + 0\cdot0012\Phi$$

Equating the above equations to zero and solving them we get the values of W, L, θ and Φ when the resistance is minimum. For this minimum value of resistance W, L and Φ are negative. Hence it is not possible to have a plough having minimum resistance under all conditions. For given value of W, L and θ, which are governed by the nature of soil, depth of ploughing and the power available, it is possible to adjust θ so that the resistance is minimum. θ appears to be the only measurement that can be adjusted to give the minimum resistance. From the minimum resistance point of view, the value of θ has been obtained for the ploughs of this experiment. Taking these values of θ, the probable depth and resistance for the respective ploughs have been calculated. The columns 6, 11 and 14 of Table I give the observed and the calculated values of R, d, θ for minimum resistance. From these value of θ, R and d it appears that Karnal, Baroda Bankura, Chotanagpur, Daltonganj and Purelia (items 4, 5, 11, 15 and 16) have their face angle (θ) within the limits of minimum resistance and can be considered to be good designs subject to the limitations of depth.

Summary

Equations showing the relation between the fundamental dimensions of a plough (weight W, length of wedge L, the face angle of the wedge θ, and the angle which the wedge makes with the horizontal at the time of ploughing Φ) and draw-bar-pull, depth and resistance per unit area of cross-section ploughed have been obtained for the soil on which the ploughs were tested. These equations appear to be of considerable value for judging the relative merits of ploughs. Further work is in progress.

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TEN PER CENT PROBABILITY OF Z AND THE VARIANCE RATIO

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Fisher and Yates [1938] have given tables of z and the variance ratio for four levels of prohibility, viz., 0·2, 0·05, 0·01 and 0·001. Values of z for $P=0{\cdot}1$ and the corresponding values of the variance ratio are presented here in Tables I and II. These will fill up an important gap between the probability levels 0·2 and 0·01.

The present tables were primarily prepared to make available to plant breeders a somewhat less stringent test of significance in replicated progeny row trials than the conventional 5 per cent level. When continuous selection is made either from crosses or from natural un-

selected material, the initially present genetic variability is gradually reduced to a level at which differences between progenies are frequently shown to be non-significant when the usual test of significance at the 5 per cent level is applied in the analysis of variance. This, however, does not necessarily mean that all genetic variance is exhausted and the material rendered unsuitable for further selection. Actually, with the reduction of genetic variability and persistence of environmental variability, detection of small genetic differences becomes more difficult, particularly in characters such as yield, where the environmental variation is considerable. Due to the limited amount of seed produced by single plants, there is also a natural limitation to the efficiency of the layout. On the other hand, it is desirable to make further selection where possible, even though it be with a lower degree of confidence in the genetic superiority of the selected progenies, rather than discard the whole material. The reason is that once a start is made with variable material, the chances of securing maximum progress are greater by accumulating small improvements resulting from continued selection in this material, than by replacing it by fresh material except when such fresh material possesses a higher initial variability. Under these conditions, a z test at ten per cent level of significance and a corresponding t test are likely to prove useful in exploring the possibility of making further selection.

The use of ten per cent values of z was suggested by Hutchinson and Panse [1937] in another and a slightly different situation in plant breeding. They recommended that nucleus stock of a strain that has been bred and distributed should be maintained by running a small progeny row trial in place of the present method of growing a number of typical, vigorous, productive plants to provide the nucleus. In analysing the data of the progeny row trial, a table of z for $P=0{\cdot}1$ will be of great value, as a plant breeder will be ready to discard a progeny if he knows that the odds are ten to one that it is lower yielding than the standard.

The present tables are based on the tables of Incomplete Beta Function for $P=0{\cdot}1$, prepared by Miss Catherine Thompson [1941]. Fisher [1935] has given the distribution of z as,

$$df=\frac{\dfrac{n_1+n_2-2}{2}\,!}{\dfrac{n_1-2}{2}\,!\;\dfrac{n_2-2}{2}\,!}\,q^{\frac{1}{2}(n_1-2)}\,(1-q)^{\frac{1}{2}(n_2-2)}\,dq$$

Where n_1 and n_2 are the degrees of freedom of the two variances to be compared and $q=\dfrac{n_1\,e^{2z}}{n_1\,e^{2z}+n_2}$.

The distribution is related to Beta-distributions through x, the argument of the Incomplete Beta Function, being equal to $\dfrac{n_2}{n_1\,e^{2z}+n_2}$, i.e. to $1-q$. The values of x are tabulated by Thompson. Conversion from x to z and to the variance ratio was a simple matter.

Values of z and the variance ratio are given in Tables I and II for all values of n_1 up to 10 and of n_2 up to 30. Beyond these points, interpolation can be made, where necessary, by using $\frac{1}{n}$ as the variable by the method given by Fisher [1936], since the values of n_1 beyond 10 and of n_2 beyond 30, given in the tables, are in harmonic progression. For larger values of n_1 and n_2 that is when n_1 is greater than 40 and n_2 greater than 60, it is desirable to calculate the values of z from Fisher's asymptotic formula as modified by Cochran [1940]. For $P=0.1$, the modified formula is:

$$Z=\frac{1{\cdot}2816}{\sqrt{h-0{\cdot}77}}-0{\cdot}6071\left(\frac{1}{n_1}-\frac{1}{n_2}\right)$$

$$\text{where}\quad \frac{2}{h}=\frac{1}{n_1}+\frac{1}{n_2}$$

In his introduction to Miss Thompson's tables, Pearson had stated that tables of the variance ratio for different levels of probability including 0·1 had been prepared and it was hoped to include them in a new edition of Tables for Statisticians and Biometricians. Since then these tables calculated by Miss Thompson have been published in Biometrica (Vol. XXXIII, pages 78-79, 1943); but the present tables which were independently computed by us are being published here, with the full concurrence of the editor of Biometrica, to make them readily available to plant breeders and other research workers in India.

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TABLE I

Distribution of z —10 per cent points

n_1 / n_2	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	1·8427	1·9510	1·9907	2·0112	2·0236	2·0320	2·0380	2·0424	2·0460	2·0488	2·0530	2·0572	2·0614	2·0636	2·0657	2·0678	2·0699	2·0720	2·0742
2	1·0716	1·0986	1·1075	1·1119	1·1146	1·1164	1·1176	1·1186	1·1193	1·1199	1·1208	1·1216	1·1225	1·1230	1·1234	1·1239	1·1243	1·1247	1·1252
3	0·8558	0·8489	0·8423	0·8378	0·8347	0·8324	0·8306	0·8293	0·8282	0·8272	0·8258	0·8244	0·8228	0·8220	0·8213	0·8204	0·8196	0·8188	0·8179
4	0·7570	0·7321	0·7164	0·7064	0·6994	0·6944	0·6905	0·6874	0·6850	0·6830	0·6799	0·6765	0·6733	0·6716	0·6698	0·6680	0·6661	0·6642	0·6623
5	0·7006	0·6648	0·6432	0·6293	0·6196	0·6125	0·6071	0·6029	0·5994	0·5966	0·5921	0·5875	0·5826	0·5801	0·5775	0·5748	0·5722	0·5694	0·5665
6	0·6643	0·6211	0·5952	0·5786	0·5669	0·5583	0·5512	0·5465	0·5422	0·5387	0·5332	0·5273	0·5212	0·5181	0·5148	0·5114	0·5080	0·5044	0·5007
7	0·6390	0·5905	0·5615	0·5427	0·5294	0·5197	0·5121	0·5061	0·5012	0·4971	0·4907	0·4839	0·4767	0·4730	0·4691	0·4651	0·4610	0·4567	0·4523
8	0·6203	0·5678	0·5364	0·5160	0·5015	0·4907	0·4824	0·4757	0·4702	0·4657	0·4585	0·4509	0·4428	0·4386	0·4342	0·4296	0·4249	0·4200	0·4148
9	0·6060	0·5504	0·5171	0·4953	0·4798	0·4682	0·4592	0·4520	0·4461	0·4411	0·4333	0·4250	0·4161	0·4114	0·4065	0·4014	0·3962	0·3906	0·3849
10	0·5947	0·5365	0·5017	0·4788	0·4624	0·4502	0·4406	0·4330	0·4266	0·4213	0·4130	0·4040	0·3944	0·3893	0·3840	0·3784	0·3727	0·3666	0·3602
11	0·5855	0·5253	0·4892	0·4653	0·4483	0·4355	0·4254	0·4173	0·4107	0·4051	0·3962	0·3867	0·3764	0·3710	0·3653	0·3593	0·3530	0·3465	0·3396
12	0·5779	0·5160	0·4788	0·4541	0·4365	0·4232	0·4127	0·4043	0·3973	0·3914	0·3821	0·3721	0·3613	0·3555	0·3494	0·3431	0·3364	0·3294	0·3219
13	0·5715	0·5082	0·4701	0·4447	0·4265	0·4128	0·4019	0·3932	0·3859	0·3798	0·3702	0·3597	0·3483	0·3422	0·3359	0·3291	0·3221	0·3145	0·3066
14	0·5660	0·5015	0·4626	0·4366	0·4180	0·4038	0·3927	0·3836	0·3762	0·3699	0·3598	0·3490	0·3371	0·3307	0·3241	0·3170	0·3096	0·3016	0·2931
15	0·5613	0·4957	0·4561	0·4296	0·4106	0·3961	0·3846	0·3754	0·3677	0·3612	0·3508	0·3396	0·3273	0·3207	0·3137	0·3063	0·2985	0·2902	0·2812
16	0·5572	0·4907	0·4504	0·4235	0·4041	0·3898	0·3776	0·3681	0·3602	0·3536	0·3429	0·3313	0·3186	0·3118	0·3046	0·2969	0·2888	0·2800	0·2706
17	0·5536	0·4863	0·4455	0·4181	0·3984	0·3833	0·3714	0·3617	0·3536	0·3468	0·3359	0·3240	0·3109	0·3039	0·2964	0·2884	0·2800	0·2709	0·2611
18	0·5504	0·4823	0·4410	0·4134	0·3933	0·3780	0·3658	0·3560	0·3477	0·3408	0·3296	0·3174	0·3040	0·2968	0·2890	0·2809	0·2721	0·2626	0·2524
19	0·5476	0·4788	0·4371	0·4091	0·3887	0·3732	0·3609	0·3508	0·3424	0·3354	0·3240	0·3116	0·2978	0·2903	0·2824	0·2740	0·2649	0·2552	0·2445
20	0·5451	0·4757	0·4336	0·4052	0·3846	0·3689	0·3564	0·3462	0·3377	0·3305	0·3189	0·3062	0·2922	0·2846	0·2764	0·2677	0·2584	0·2483	0·2373
21	0·5427	0·4728	0·4304	0·4017	0·3809	0·3650	0·3524	0·3420	0·3334	0·3261	0·3143	0·3014	0·2870	0·2792	0·2710	0·2620	0·2525	0·2421	0·2306
22	0·5407	0·4703	0·4275	0·3986	0·3776	0·3615	0·3487	0·3382	0·3295	0·3220	0·3101	0·2970	0·2824	0·2744	0·2659	0·2568	0·2470	0·2363	0·2245
23	0·5388	0·4679	0·4248	0·3957	0·3745	0·3582	0·3453	0·3347	0·3259	0·3184	0·3062	0·2929	0·2781	0·2700	0·2613	0·2520	0·2419	0·2310	0·2188
24	0·5370	0·4658	0·4224	0·3931	0·3717	0·3553	0·3422	0·3315	0·3226	0·3150	0·3027	0·2892	0·2741	0·2658	0·2570	0·2475	0·2373	0·2260	0·2135
25	0·5354	0·4638	0·4201	0·3906	0·3691	0·3525	0·3394	0·3286	0·3195	0·3118	0·2994	0·2857	0·2704	0·2621	0·2531	0·2434	0·2329	0·2214	0·2086
26	0·5339	0·4619	0·4181	0·3884	0·3667	0·3500	0·3367	0·3258	0·3167	0·3089	0·2964	0·2825	0·2670	0·2585	0·2494	0·2396	0·2289	0·2171	0·2039
27	0·5326	0·4603	0·4162	0·3863	0·3645	0·3477	0·3343	0·3233	0·3141	0·3063	0·2936	0·2796	0·2639	0·2552	0·2460	0·2360	0·2251	0·2131	0·1996
28	0·5313	0·4587	0·4144	0·3844	0·3624	0·3455	0·3320	0·3210	0·3117	0·3038	0·2910	0·2768	0·2609	0·2522	0·2428	0·2327	0·2216	0·2093	0·1955
29	0·5301	0·4572	0·4128	0·3826	0·3605	0·3435	0·3299	0·3188	0·3094	0·3015	0·2886	0·2742	0·2582	0·2493	0·2398	0·2295	0·2182	0·2057	0·1916
30	0·5290	0·4559	0·4112	0·3809	0·3587	0·3416	0·3280	0·3167	0·3073	0·2993	0·2862	0·2718	0·2556	0·2467	0·2370	0·2266	0·2151	0·2024	0·1880
40	0·5211	0·4461	0·4001	0·3688	0·3457	0·3279	0·3136	0·3018	0·2919	0·2834	0·2696	0·2541	0·2366	0·2268	0·2162	0·2046	0·1916	0·1770	0·1599
60	0·5132	0·4363	0·3890	0·3567	0·3328	0·3142	0·2993	0·2868	0·2764	0·2674	0·2526	0·2360	0·2170	0·2063	0·1945	0·1814	0·1665	0·1491	0·1279
120	0·5055	0·4266	0·3780	0·3446	0·3198	0·3005	0·2848	0·2718	0·2606	0·2511	0·2354	0·2175	0·1967	0·1848	0·1716	0·1565	0·1389	0·1174	0·0880
∞	0·4977	0·4170	0·3671	0·3326	0·3069	0·2866	0·2702	0·2565	0·2448	0·2346	0·2178	0·1984	0·1755	0·1622	0·1470	0·1293	0·1075	0·0779	0·0000

TABLE II

Variance ratio—10 per cent points of e^{2z}

n_2 \ n_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	39·86	49·50	53·59	55·83	57·24	58·20	58·91	59·44	59·86	60·20	60·70	61·22	61·74	62·00	62·26	62·53	62·79	63·06	63·33
2	8·53	9·00	9·16	9·24	9·29	9·32	9·35	9·37	9·38	9·39	9·41	9·42	9·44	9·45	9·46	9·47	9·47	9·48	9·49
3	5·54	5·46	5·39	5·34	5·31	5·28	5·27	5·25	5·24	5·23	5·22	5·20	5·18	5·18	5·17	5·16	5·15	5·14	5·13
4	4·54	4·32	4·19	4·11	4·05	4·01	3·98	3·96	3·94	3·92	3·90	3·87	3·84	3·83	3·82	3·80	3·79	3·78	3·76
5	4·06	3·78	3·62	3·52	3·45	3·40	3·37	3·34	3·32	3·30	3·27	3·24	3·21	3·19	3·17	3·16	3·14	3·12	3·10
6	3·78	3·46	3·29	3·18	3·11	3·05	3·01	2·98	2·96	2·94	2·90	2·87	2·84	2·82	2·80	2·78	2·76	2·74	2·72
7	3·59	3·26	3·07	2·96	2·88	2·83	2·78	2·75	2·72	2·70	2·67	2·63	2·60	2·58	2·56	2·54	2·51	2·49	2·47
8	3·46	3·11	2·92	2·81	2·73	2·67	2·62	2·59	2·56	2·54	2·50	2·46	2·42	2·40	2·38	2·36	2·34	2·32	2·29
9	3·36	3·01	2·81	2·69	2·61	2·55	2·50	2·47	2·44	2·42	2·38	2·34	2·30	2·28	2·26	2·23	2·21	2·18	2·16
10	3·28	2·92	2·73	2·60	2·52	2·46	2·41	2·38	2·35	2·32	2·28	2·24	2·20	2·18	2·16	2·13	2·11	2·08	2·06
11	3·22	2·86	2·66	2·54	2·45	2·39	2·34	2·30	2·27	2·25	2·21	2·17	2·12	2·10	2·08	2·05	2·03	2·00	1·97
12	3·18	2·81	2·61	2·48	2·39	2·33	2·28	2·24	2·21	2·19	2·15	2·10	2·06	2·04	2·01	1·99	1·96	1·93	1·90
13	3·14	2·76	2·56	2·43	2·35	2·28	2·23	2·20	2·16	2·14	2·10	2·05	2·01	1·98	1·96	1·93	1·90	1·88	1·85
14	3·10	2·73	2·52	2·40	2·31	2·24	2·19	2·15	2·12	2·10	2·05	2·01	1·96	1·94	1·91	1·89	1·86	1·83	1·80
15	3·07	2·70	2·49	2·36	2·27	2·21	2·16	2·12	2·09	2·06	2·02	1·97	1·92	1·90	1·87	1·84	1·82	1·79	1·76
16	3·05	2·67	2·46	2·33	2·24	2·18	2·13	2·09	2·06	2·03	1·98	1·94	1·89	1·87	1·84	1·81	1·78	1·75	1·72
17	3·03	2·64	2·44	2·31	2·22	2·15	2·10	2·06	2·03	2·00	1·96	1·91	1·86	1·84	1·81	1·78	1·75	1·72	1·69
18	3·01	2·62	2·42	2·29	2·20	2·13	2·08	2·04	2·00	1·98	1·93	1·89	1·84	1·81	1·78	1·75	1·72	1·69	1·66
19	2·99	2·61	2·40	2·27	2·18	2·11	2·06	2·02	1·98	1·96	1·91	1·86	1·81	1·79	1·76	1·73	1·70	1·67	1·63
20	2·98	2·59	2·38	2·25	2·16	2·09	2·04	2·00	1·96	1·94	1·89	1·84	1·79	1·77	1·74	1·71	1·68	1·64	1·61
21	2·96	2·58	2·36	2·23	2·14	2·08	2·02	1·98	1·95	1·92	1·88	1·83	1·78	1·75	1·72	1·69	1·66	1·62	1·59
22	2·95	2·56	2·35	2·22	2·13	2·06	2·01	1·97	1·93	1·90	1·86	1·81	1·76	1·73	1·70	1·67	1·64	1·60	1·57
23	2·94	2·55	2·34	2·21	2·12	2·05	2·00	1·95	1·92	1·89	1·84	1·80	1·74	1·72	1·69	1·66	1·62	1·59	1·55
24	2·93	2·54	2·33	2·20	2·10	2·04	1·98	1·94	1·91	1·88	1·83	1·78	1·73	1·70	1·67	1·64	1·61	1·57	1·53
25	2·92	2·53	2·32	2·18	2·09	2·02	1·97	1·93	1·90	1·87	1·82	1·77	1·72	1·69	1·66	1·63	1·59	1·56	1·52
26	2·91	2·52	2·31	2·17	2·08	2·01	1·96	1·92	1·88	1·86	1·81	1·76	1·71	1·68	1·65	1·62	1·58	1·54	1·50
27	2·90	2·51	2·30	2·17	2·07	2·00	1·95	1·91	1·87	1·84	1·80	1·75	1·70	1·67	1·64	1·60	1·57	1·53	1·49
28	2·89	2·50	2·29	2·16	2·06	2·00	1·94	1·90	1·86	1·84	1·79	1·74	1·68	1·66	1·62	1·59	1·56	1·52	1·48
29	2·89	2·50	2·28	2·15	2·06	1·99	1·94	1·89	1·86	1·83	1·78	1·73	1·68	1·65	1·62	1·58	1·55	1·51	1·47
30	2·88	2·49	2·28	2·14	2·05	1·98	1·93	1·88	1·85	1·82	1·77	1·72	1·67	1·64	1·61	1·57	1·54	1·50	1·46
40	2·84	2·44	2·23	2·09	2·00	1·93	1·87	1·83	1·79	1·76	1·72	1·66	1·60	1·57	1·54	1·51	1·47	1·42	1·38
60	2·79	2·39	2·18	2·04	1·95	1·88	1·82	1·78	1·74	1·71	1·66	1·60	1·54	1·51	1·48	1·44	1·40	1·35	1·29
120	2·75	2·35	2·13	1·99	1·90	1·82	1·77	1·72	1·68	1·65	1·60	1·[illegible]4	1·48	1·45	1·41	1·37	1·32	1·26	1·19
∞	2·71	2·30	2·08	1·94	1·85	1·77	1·72	1·67	1·63	1·60	1·55	1·49	1·42	1·38	1·34	1·30	1·24	1·17	1·00

STATISTICAL NOTES FOR AGRICULTURAL WORKERS

No. 26. INFLUENCE OF DATES OF PLANTING AND SPACINGS ON SOME WINTER VARIETIES OF RICE

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(With three text-figures)

The increase in the production of rice rests in general with the evolution of high-yielding strains suitable for different localities, and if suitable cultural methods are adopted for growing these strains the yield could further be enhanced. The study of the effect of different cultural treatments on the rice plant is therefore a very important problem for all rice growing tracts.

With a view to having a precise idea of the effects of the cultural factors, such as, time of planting, age of seedling, spacing, number of seedlings per hole, etc. on the yield of some selected strains of rice of different ripening habits under the conditions obtaining at the Dacca Farm, a series of cultural experiments were laid out in 1936-37 and repeated for a number of years successively. The present paper deals with the results of one of the experiments which was conducted in five successive years, from 1936-37 to 1940-41. It involved three factors, viz. date of planting, strain of rice and spacing.

Material and method

The experiment comprised of the following three sets of factors:

(1) *Three strains of winter rice*:
- (*i*) Latisail—with early maturing habit.
- (*ii*) Indrasail—with medium maturing habit.
- (*iii*) Tilakkachari—with late maturing habit.

(2) *Six dates of planting*: (*i*) 1 July, (*ii*) 16 July, (*iii*) 1 August, (*iv*) 16 August, (*v*) 1 September, (*vi*) 16 September.

(3) *Three spacings*: (*i*) Six inches, (*ii*) Nine inches, (*iii*) Twelve inches.

The factors gave altogether $6\times3\times3$ or 54 different treatments. Each treatment was replicated three times giving a total of 162 unit plots, each measuring 9 ft. $\times$ 20 ft. or about 1/240th acre in area.

Of the three factors included in this experiment, the first alone, namely, varieties, is qualitative. In the case of this factor our object is only to compare the three varieties among themselves and decide which is the best variety and so on. But our object in the case of the second factor, namely, date of planting, is not merely to make a comparison between the six selected dates; for, these dates are not likely to be more important than any other six dates separated by fortnightly intervals belonging to the range of time July to September. Our problem may be either (*i*) to predict the yield of the crop if the planting had been done on any date falling within the range of time covered from 1 July to 16 September, or (*ii*) to know whether the yield reaches a maximum on some date within this period. In the second case we will be proceeding on the hypothesis that the yield will vary regularly as in a smooth curve having a single maximum at a date lying within the range of time covered in the experiment. We may therefore say that we are trying to fix the optimal date of the yield curve which we have previous reason to believe will lie somewhere between 1 July and 16 September. In experiments of this nature, careful planning is necessary, in the choice of the range and the number of points of time selected for experimental study. After doing the experiment for two or more years, it will be possible to arrive at a first approximation of the optimal date, and if the experiment is modified by shortening the range of the points we will be able to fix the optimal date with greater precision, thus affording a gradual close-up study of this date. On the other hand, if the object of the experiment is merely to supply a sort of yield table for various dates of planting, irrespective of whether an optimal date exists or not, it will be necessary to select a large number of dates over as wide a range of time as is allowable under practical considerations.

What have been said above regarding the dates of planting applies with equal force to the third factor, namely *spacing*. We can consider the three spacings selected, namely 6 in., 9 in., 12 in. as only convenient points to study the yield curve for a continuous range of spacings. Since three ordinates of the curve have been selected for study we are allowing for detection of any curvature in the curve which gives it a single maximum. If this optimal spacing lies between 6 in. and 12 in. it could be determined with some reliability. But if the optimal spacing falls outside the range, the three points selected will lie in one limb of the curve

almost along a straight line leading us to a possibly wrong conclusion that there is no optimal spacing at all. The interpretation of yield curve for this factor is complicated by the fact that for shorter spacings, proportionately more plants will be growing in the plot, resulting in greater total yield, unless the yield per plant is reduced as a result of closer spacing. Two different questions may be asked, namely, (*i*) what is the optimal spacing and hence the number of plants when a certain specified area is available for cultivation, (*ii*) what is the optimal spacing and hence the area of plot required when a certain specified number of plants is available for cultivation. Generally, (*i*) is of more frequent occurrence than (*ii*), but the answer to both questions will be simultaneously available from our experiment.

Layout

The experiment was laid out in a long stretch of land of almost uniform fertility, in three blocks of equal size, each containing one complete set of all the treatments. The blocks were separated from one another by bunds for the facility of agricultural operations and to maintain in all the three blocks approximately the same depth of water during the growth of the crop.

To facilitate cultural operations, the plots of the same date of planting were, first of all, laid out in long rows (or strips) and the positions occupied by six such rows corresponding to the different dates of planting, within each block, were determined at random. Likewise and for the same reason the plots under the three different strains of rice were distributed separately into three compact strips running across the rows and their respective positions within each block were fixed up at random. Ultimately the three different spacings were assigned at random within each combination of date of planting and strain of rice. The layout plan of the experiment is shown in Fig. 1, from which it will be seen that we have adopted a combination of strip and split plot arrangements.

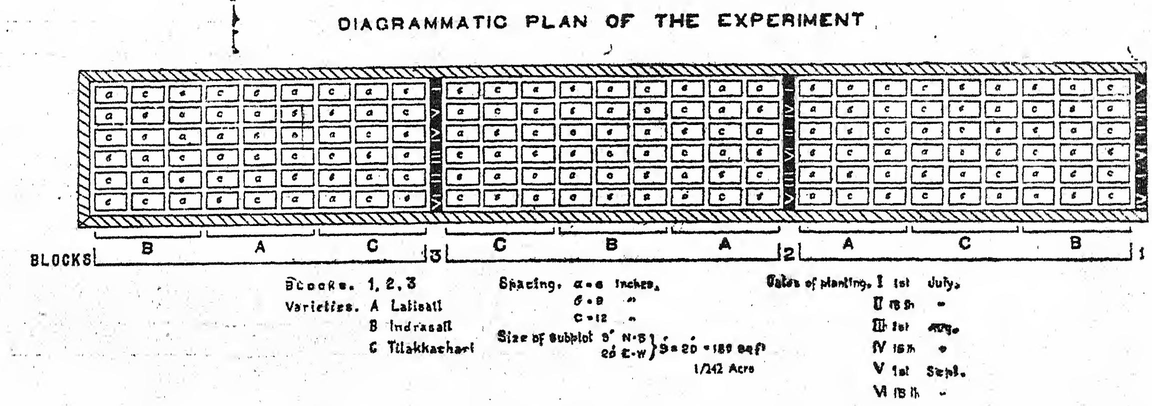

Fig. 1. Layout plan

The dates of planting and the strains of rice were the whole plot or strip treatments while spacing was the sub-plot treatment each with its appropriate error. For the weights of grain and straw the whole produce from each unit plot was gathered.

Rainfall

The five-day totals of rainfall in the Dacca Farm during the season for each of the five years, and the total number of rainy days during each five-day period, are shown in Table I. The normal rainfall for each month is also given to help study of seasonal variation in yield.

Analysis of data and discussion of results

The analysis of variance of the yields of grain and straw of all the five years are shown in Tables IIA and IIB. To economize space only the values of variances have been given. There are four different error variances associated with soil variation between plots of the four different sizes occurring within each block. The various main effects and interactions have been so arranged that variance due to each of them can be tested for significance against its appropriate Error Variance, which appears just below it. The error variances have been numbered (I), (II), (III), (IV) for identification.

From Table IIA, we find that the only effects on yield of grain which were significant in every year are variations between dates of planting, and between spacings and the interaction between dates of planting and spacings. All of them are highly significant at 1 per cent level. In 1937-38 alone some of the interactions between strains of rice, date of planting and spacing came out significant, but being an isolated result we need not attach any significance to it.

Table I

Five-day totals of rainfall in inches at Dacca Farm

Period	1936-37		1937-38		1938-39		1939-40		1940-41		Normal rainfall for the month
	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	
March											
1—5	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·69	2	
6—10	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·04	1	
11—15	Nil	Nil	Nil	Nil	0·40	1	Nil	Nil	0·10	1	
16—20	0·13	1	Nil	Nil	Nil	Nil	0·32	1	0·85	2	
21—25	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·71	2	
26—31	1·78	2	Nil	Nil	Nil	Nil	0·98	2	0·62	2	
Total	1·91	3	Nil	Nil	0·40	1	1·30	3	3·01	10	1·05
April											
1—5	0·25	1	Nil	Nil	0·06	1	Nil	Nil	Nil	Nil	
6—10	1·36	2	Nil	Nil	0·81	1	0·16	2	Nil	Nil	
11—15	Nil	Nil	Nil	Nil	0·40	1	Nil	Nil	Nil	Nil	
16—20	1·17	2	1·12	1	0·34	1	Nil	Nil	0·56	1	
21—25	Nil	Nil	0·27	2	1·71	3	0·08	1	0·17	1	
26—30	Nil	Nil	0·23	2	1·99	3	0·04	1	Nil	Nil	
Total	2·78	5	1·62	5	5·31	10	0·28	4	0·73	2	3·22
May											
1—5	0·48	2	Nil	Nil	4·08	4	0·66	1	0·17	1	
6—10	2·34	2	2·96	4	0·45	4	2·42	4	1·30	1	
11—15	0·57	3	Nil	Nil	2·37	2	Nil	Nil	0·55	2	
16—20	1·54	2	5·41	4	1·75	3	0·99	2	0·67	1	
21—25	0·10	1	3·52	3	2·70	2	1·27	1	4·72	5	
26—31	5·78	4	2·34	5	8·51	5	0·49	1	1·19	1	
Total	10·81	14	14·23	16	19·86	20	5·83	9	8·60	11	10·09
June											
1—5	3·94	5	1·10	4	0·11	3	1·30	3	Nil	Nil	
6—10	1·59	3	0·29	3	0·25	3	0·97	3	1·91	2	
11—15	0·85	5	0·58	4	2·96	5	0·97	4	4·46	5	
16—20	1·10	3	4·60	4	2·02	4	0·53	5	3·32	3	
21—25	1·47	3	2·01	3	1·64	3	3·71	5	Nil	Nil	
26—30	1·72	3	0·46	3	4·71	3	2·34	5	0·23	3	
Total	10·67	22	9·04	21	11·69	21	9·82	25	9·92	13	11·56
July											
1—5	1·53	3	0·40	4	0·15	1	0·99	2	1·80	5	
6—10	2·59	4	4·05	3	3·13	4	0·46	5	0·62	3	
11—15	4·86	5	1·40	5	1·11	5	8·76	5	0·05	1	
16—20	1·49	5	0·97	4	0·97	4	0·74	5	2·78	4	
21—25	1·09	2	0·52	3	1·19	3	1·00	4	0·44	3	
26—31	3·96	6	1·91	5	6·13	5	18·97	6	0·74	4	
Total	15·52	25	9·25	24	12·68	22	30·92	27	6·43	20	13·31
August											
1—5	4·15	5	0·78	4	4·60	4	13·09	5	3·22	4	
6—10	2·87	5	7·01	5	8·09	4	1·42	4	4·77	4	
11—15	1·01	1	6·32	5	1·27	4	1·87	4	0·62	4	
16—20	3·10	5	0·13	3	2·05	3	1·49	4	0·06	1	
21—25	1·71	3	2·07	4	1·52	4	0·54	4	0·34	3	
26—31	1·72	4	2·69	5	0·75	4	0·70	3	2·49	4	
Total	14·56	23	19·00	26	18·28	23	19·11	24	11·50	20	14·03
September											
1—5	0·59	3	0·75	3	3·26	5	1·01	4	4·79	3	
6—10	1·60	4	1·63	3	1·05	2	2·17	4	2·70	5	
11—15	4·34	4	0·48	4	2·06	3	1·67	5	1·13	3	
16—20	1·66	2	0·47	2	6·96	5	1·95	2	0·09	2	
21—25	1·38	1	1·85	4	0·07	1	2·34	3	6·09	5	
26—30	Nil	Nil	3·04	3	Nil	Nil	1·07	2	0·12	2	
Total	9·57	14	8·22	19	13·40	16	10·21	20	14·92	20	9·90
October											
1—5	1·85	3	0·20	3	Nil	Nil	4·04	4	Nil	Nil	
6—10	0·11	1	1·11	2	0·02	1	5·71	2	Nil	Nil	
11—15	1·29	2	0·51	2	0·71	2	0·08	1	Nil	Nil	
16—20	0·18	2	Nil	Nil	1·51	3	0·07	1	Nil	Nil	
21—25	Nil	Nil	Nil	Nil	1·21	2	3·76	3	3·47	3	
26—31	Nil	Nil	Nil	Nil	Nil	Nil	0·21	2	Nil	Nil	
Total	3·43	8	1·82	7	3·45	8	13·87	13	3·47	3	4·86
November											
1—5	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
6—10	Nil	Nil	Nil	Nil	0·20	1	Nil	Nil	Nil	Nil	
11—15	0·08	1	Nil	Nil	0·70	2	Nil	Nil	Nil	Nil	
16—20	0·72	2	Nil	Nil	Nil	Nil	Nil	Nil	0·14	1	
21—25	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
26—30	Nil	Nil	1·18	2	Nil	Nil	0·01	1	Nil	Nil	
Total	0·80	3	1·18	2	0·90	3	0·01	1	0·14	1	1·06

TABLE I—*contd.*

Period	1936-37		1937-38		1938-39		1939-40		1940-41		Normal rainfall for the month
	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	Rain-fall	No. of rainy days	
December											
1—5	Nil	Nil	0·05	1	Nil	Nil	Nil	Nil	Nil	Nil	
6—10	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
11—15	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
16—20	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
21—25	0·02	1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
26—31	0·04	1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
Total	0·06	2	0·05	1	Nil	Nil	Nil	Nil	Nil	Nil	0·21
January											
1—5	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
6—10	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
11—15	Nil	Nil	0·39	1	Nil	Nil	Nil	Nil	Nil	Nil	
16—20	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
21—25	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·14	1	
26—31	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0·59	1	
Total	Nil	Nil	0·39	1	Nil	Nil	Nil	Nil	0·73	2	0·12
February											
1—5	Nil	Nil	0·05	1	Nil	Nil	Nil	Nil	Nil	Nil	
6—10	0·09	1	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
11—15	1·85	3	1·06	2	0·45	1	0·31	1	Nil	Nil	
16—20	Nil	Nil	0·11	1	Nil	Nil	Nil	Nil	2·95	1	
21—25	0·74	2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	
26—28	Nil	Nil	Nil	Nil	Nil	Nil	1·36	2	Nil	Nil	
**29	...	...	...	...	...	...	0·47**	1	...	...	
Total	2·68	6	1·22	4	0·45	1	2·14	4	2·95	1	1·32

** In case of Leap-year only

In case of yield of straw also, Table IIB points to similar conclusions as in the case of yield of grain for the main effects of dates and spacings. But their interaction is not significant except in one year. An additional feature is that the variations due to strains of rice is significant at 5 per cent level in three out of the five years. The interaction : Dates of Planting × Strains of rice, is significant at 1 per cent level in two years, whereas the three-factor interaction is significant at 5 per cent level in only one year.

TABLE IIA

Analysis of variance (yield of grain in tolas)

	Degrees of free-dom	Variance				
		1936-37	1937-38	1938-39	1939-40	1940-41
Block	2	81482·34	72258·67	10676·08	78413·57	81443·19
Strain of rice	2	92740·63	210426·89	19677·00	62027·46	42192·12
Error (I)	4	53151·38	38492·11	17937·65	9905·51	25239·21
Date of planting	5	446908·51**	617315·36**	362845·34**	329354·27**	525175·37**
Error (II)	10	13999·35	24433·10	21490·15	18774·13	21195·87
Date of planting × Strain of rice	10	13029·22	17287·81*	6964·41	13787·02	12703·41
Error (III)	20	6279·25	6778·20	11341·17	5804·58	12308·17
Spacing	2	35955·28**	135574·52**	84746·45**	90535·80**	78208·03**
Spacing × Date of planting	10	14234·69**	15000·42**	18798·30**	18686·35**	20356·74**
Spacing × Strain of rice	4	4350·11	1570·07	5666·36	3856·04	6484·79
Spacing × Strain of rice × Date of planting.	20	3941·37	15178·19**	5400·99	4164·99	309·77
Error (IV)	72	3589·86	6982·82	6359·57	3202·01	5448·02

N. B.—Items marked with one and two asterisks are both significant, the former at the level of 5 per cent probability and the latter at the level of 1 per cent probability

The determination of straw yield was not done as accurately as in the case of grain. After threshing, both grain and straw were left in the sun and their weights were taken when dry. In the former case the drying was done for quite a long time with such care that more or less a constant weight was reached, while in the case of the latter so much care could not be taken. There was therefore no guarantee that the extent of drying of straw was comparable in each season. The standard error per plot for each of the different plot sizes has been calculated as a percentage of the mean yield for both grain and straw in each of the five years. This is given in Table III. It will be seen that the standard error was greater for straw than for grain. Also while the values of S. E. per cent for the various years are more or less steady for grain, there are wide fluctuations in the case of straw.

TABLE II B

Analysis of variance (yield of straw in tolas)

	Degrees of freedom	Variance				
		1936-37	1937-38	1938-39	1939-40	1940-41
Block	2	383285·34	1161858·25	186941·82	837551·08	430433·91
Strain of rice	2	1361896·45*	787239·43	1458553·84	975029·79*	1751933·56*
Error (I)	4	132180·48	483906·39	334731·64	91058·95	104037·55
Date of planting	5	3159798·02**	5418854·55**	4120980·15**	2558610·52**	4462671·27**
Error (II)	10	46059·97	532764·04	347809·60	218019·97	294997·59
Date of planting × Strain of rice	10	101429·97**	92033·62	73283·86	16700·90	178403·57**
Error (III)	20	20639·78	81066·52	82291·08	16231·73	35193·14
Spacing	2	950824·23**	2371421·80**	637523·30**	634277·94**	698418·74**
Spacing × Date of planting	10	13377·75	74885·15	27116·64	10506·27	64789·65*
Spacing × Strain of rice	4	22535·34	46467·73	37471·46	18840·66	3767·60
Spacing × Strain of rice × Date of planting	20	26492·75*	2103·43	34199·78	17363·72	23099·62
Error (IV)	72	15857·56	51618·28	61076·69	12959·88	15868·47

N. B.—Items marked with one and two asterisks are both significant, the former at the level of 5 per cent probability and the latter at the level of 1 per cent probability

TABLE III

Standard error per cent per plot

Year	Error I		Error II		Error III		Error IV	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
1936-37	52·14	55·04	26·75	32·40	17·92	21·75	13·55	19·07
1937-38	37·97	59·97	30·24	62·93	15·93	24·55	16·17	19·59
1938-39	30·28	70·27	33·15	71·63	24·08	34·85	18·03	30·01
1939-40	24·42	63·86	33·62	98·79	18·70	26·96	13·79	24·08
1940-41	40·53	48·65	37·14	81·89	28·32	28·29	19·08	19·00

Since only the two factors, date of planting and spacing indicated significant effects every year on the yield of grain and straw the mean yield in tolas per plot for each combination of these two factors are given in Tables IVA and IVB. The standard errors for comparing the means of dates of planting and of spacings are separately given.

We note that the yield of grain is greater for the second date of planting than for the first date; and for the third and later dates, the yield registers a progressive fall. But yield of straw is greatest for the earliest date of planting. Similarly out of the three spacings, 6 in. gives the best yield for both grain and straw; the wider spacings of 9 in. and 12 in. giving progressively lower yield. This result is consistent over all the five years, although the five seasons give widely varying mean yields, namely, 442, 517, 442, 407 and 392 for grain and

661, 1160, 823, 673 and 663 for straw. To test whether these variations between years and their interactions with other factors are significant a combined analysis of variance of the five years data can be done, provided the error variances are not significantly different. This latter point was investigated by an approximate Chi-square (χ^2) test introduced by Yates and Cochran [1938]. The values of χ^2 are given in Table V. We find that none of the values of Chi-square is significant in the case of grain, which means the error variances are comparable and a pooled analysis of variance admissible. In the case of straw the pooled analysis is not valid and was not therefore undertaken.

Table IV A

Dates of planting × Spacings (mean yield of grain in tolas per plot)

Spacings	Dates of planting						Mean	Standard Error (Spacings)
	July 1 (I)	July 16 (II)	Aug. 1 (III)	Aug. 16 (IV)	Sept. 1 (V)	Sept. 16 (VI)		
1936-37								
(*a*) 6 in.	504·11	583·22	519·89	485·89	433·44	292·78	469·89	8·17
(*b*) 9 in.	557·78	556·89	499·00	441·11	347·22	226·89	438·15	
(*c*) 12 in.	568·44	591·00	470·33	414·22	292·78	175·89	418·78	
Mean	543·44	577·07	496·41	447·07	357·82	231·85	442·27	
Standard Error (dates of planting)	22·77							
1937-38								
(*a*) 6 in.	639·11	683·11	680·67	567·78	495·56	328·67	565·81	11·37
(*b*) 9 in.	655·11	662·00	619·56	503·78	452·89	219·78	518·85	
(*c*) 12 in.	636·89	603·56	566·00	396·67	325·33	265·56	465·67	
Mean	643·70	649·56	622·07	489·41	424·52	271·33	516·78	
Standard Error (dates of planting)	30·08							
1938-39								
(*a*) 6 in.	516·67	581·11	521·11	477·78	470·00	308·89	479·26	10·85
(*b*) 9 in.	498·89	593·33	462·22	482·22	394·44	251·11	447·04	
(*c*) 12 in.	576·67	504·44	451·11	410·00	303·33	157·22	400·46	
Mean	530·74	559·63	478·15	456·67	389·26	239·07	442·25	
Standard Error (dates of planting)	28·21							
1939-40								
(*a*) 6 in.	472·11	518·33	489·22	468·44	420·67	290·67	443·24	7·71
(*b*) 9 in.	512·00	529·56	153·11	431·00	335·56	237·67	416·48	
(*c*) 12 in.	545·56	491·11	400·11	338·22	248·56	153·46	362·83	
Mean	509·89	513·00	447·48	412·52	334·93	227·26	407·50	
Standard Error (dates of planting)	26·37							
1940-41								
(*a*) 6 in.	487·89	580·11	514·44	396·78	401·78	200·11	430·19	10·04
(*b*) 9 in.	493·00	540·56	428·78	400·89	325·11	161·67	391·67	
(*c*) 12 in.	511·56	507·11	418·22	339·78	232·22	115·56	354·07	
Mean	497·48	542·59	453·82	379·15	319·70	159·11	391·98	
Standard Error (dates of planting)	28·02							

Table VI gives the pooled analysis of variance for grain yield. The appropriate error variance to test the effect of years is the item blocks × years with 8 d. f. We find that when so tested the effect of years is highly significant. There are only four other effects, namely, main effect of dates, main effect of spacings, main effect of strains and the interaction between date and spacing which are all highly significant. It is very important to note that there is no interaction between years and any of the factors, strains, dates or spacings. We have therefore got a definite picture of the influences of date of planting and of spacing which should be applicable to a wide range of seasonal conditions obtainable at Dacca if the five years under consideration give a fair sample of seasons.

TABLE IV B

Dates of planting × Spacings (mean yield of straw in tolas per plot)

Spacings	July 1 (I)	July 16 (II)	Aug. 1 (III)	Aug. 16 (IV)	Sept. 1 (V)	Sept. 16 (VI)	Mean	Standard Error (Spacings)
1936-37								
(a) 6 in.	1321·11	1132·22	860·00	711·11	487·78	352·78	810·83	17·14
(b) 9 in.	1066·67	904·44	671·11	476·11	299·44	252·22	611·67	
(c) 12 in.	997·78	821·11	689·44	421·11	248·89	177·78	559·35	
Mean	1128·52	952·59	740·19	536·11	345·37	260·93	660·62	
Standard Error (dates of planting)	41·32							
1937-38								
(a) 6 in.	1868·44	1693·33	1630·22	1463·11	794·67	752·00	1366·96	30·92
(b) 9 in.	1859·00	1336·22	1336·89	1160·00	739·56	562·67	1164·63	
(c) 12 in.	1595·56	1088·44	1115·56	890·67	529·78	467·56	947·93	
Mean	1772·15	1372·67	1360·89	1171·26	688·00	594·07	1159·84	
Standard Error (dates of planting)	140·48							
1938-39								
(a) 6 in.	1462·22	1232·22	886·67	911·11	607·78	482·22	930·19	33·64
(b) 9 in.	1388·33	1167·78	714·44	755·56	507·78	427·78	826·94	
(c) 12 in.	1437·78	1035·56	567·78	588·89	403·33	266·67	712·96	
Mean	1421·67	1145·19	722·96	751·85	506·30	392·22	823·36	
Standard Error (dates of planting)	113·50							
1939-40								
(a) 6 in.	1354·44	935·56	728·89	736·67	501·11	440·00	784·63	15·49
(b) 9 in.	1216·11	808·89	603·33	577·78	395·56	412·22	669·98	
(c) 12 in	1058·33	705·00	555·56	471·11	308·89	297·78	566·11	
Mean	1209·63	816·48	629·26	558·15	401·85	383·33	672·62	
Standard Error (dates of planting)	89·99							
1940-41								
(a) 6 in.	1380·00	1258·89	817·78	546·00	467·78	258·11	788·09	17·14
(b) 9 in.	1317·78	866·67	504·44	490·56	364·11	272·78	636·06	
(c) 12 in.	1200·00	835·56	553·56	395·33	264·89	142·78	565·35	
Mean	1299·26	987·04	625·26	477·30	365·59	224·56	663·17	
Standard Error (dates of planting)	104·53							

TABLE V

Values of χ^2 for Error Variances

Years	Error (I)		Error (II)		Error (III)		Error (IV)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
1936-37	7·34	2·31	7·01	1·60	12·56	8·77	35·90	36·27
1937-38	5·28	8·45	12·22	18·50*	13·56	34·43*	69·83	118·07*
1938-39	2·48	5·84	10·75	12·08	22·68	34·95*	63·60	139·71*
1939-40	1·37	1·59	9·40	7·57	11·61	6·89	32·02	29·64
1940-41	3·49	1·80	10·61	10·24	24·62	14·95	54·48	36·30
Degrees of freedom	4		10		20		72	

*Significant at 5 per cent level

TABLE VI

Combined analysis of variance 5 years (yield of grain in tolas per plot)

	Degrees of freedom	Sum of squares	Variance
Blocks	2	511198·37	255599·19
Years	4	1501149·44	375287·36**
Blocks × Years	8	137349·33	17168·67
Strains of rice	2	391931·35	195965·67**
Strains of rice × Years	8	462196·87	57774·61
Error (I)	20	578903·52	28945·18
Dates of planting	5	11147209·17	2229441·83**
Dates of planting × Years	20	260785·11	13039·25
Error (II)	50	998925·95	19978·52
Strains of rice × Dates of planting	10	260161·27	26016·17
Strains of rice × Dates of planting × Years	40	377557·47	9438·93
Error (III)	100	850227·29	8502·27**
Spacings	2	809074·63	404537·31
Spacings × Strains of rice	4	31600·48	7900·22
Spacings × Dates of planting	10	578710·79	57871·08**
Spacings × Dates of planting × Strains of rice	20	175098·77	8754·94
Spacings × Years	8	40965·52	5120·69
Spacings × Strains of rice × Years	16	56205·67	3512·85
Spacings × Dates of planting × Years	40	192054·24	4801·36
Spacings × Dates of planting × Strains of rice × Years	80	504709·68	6308·87
Error(IV)	360	1841924·56	5116·46
Total	809	21707939·48	..

Since the main effect of strains of rice when averaged over the five seasons has come out significant, it is necessary to indicate which variety is best. Table VII gives the mean yield per plot of each variety in each of the five seasons.

TABLE VII

Mean yield of grain of the varieties (in tolas per plot)

Year	Strains of Rice			Critical difference at 5% level	Varieties which are significantly different
	A. Latisail	B. Indra-sail	C. Tilakka-chari		
1936-37	476·52	396·20	454·09	123·17	nil
1937-38	584·70	503 70	461·93	104·82	A > C
1938-39	425·93	463·24	437·59	68·23	nil
1939-40	446·57	390·15	385·83	53·16	A B; A > C
1940-41	422·43	367·48	386·02	84 86	nil
All years	471·23	424·15	425·09	30·54	A > B; A > C

The influence of date of planting and of spacing require a closer study. It is not enough if we decide in favour of one among the six dates chosen, or one among the three spacings. Both these factors are measurable and it is quite possible that the yield can be expressed as a mathematical function of the date or of spacing or of both. Once that mathematical function is determined with precision, the picture becomes objective and more complete than what the figures of Table IV could give. We can, in fact, pose the question, what date of planting between 1 July and 16 September is likely to give the maximum yield for grain. What spacing lying between 6 and 12 inches will likewise give the best yield? Will this optimum date vary with the spacing or the optimum spacing vary with the date as is possible on account of the interaction between date and spacing? All these questions have been answered in the further analysis taken up below.

Since there are six dates of planting, which though not exactly equidistant may be assumed to be so, we can plot graphs marking the dates along the axis of X and yield along the axis of Y. Four graphs can be obtained for each spacing and the mean of the 3 spacings as shown in Fig. 2. A fifth degree polynomial can be fitted at the most, but usually even a smaller degree curve gives quite an adequate fit. Another set of seven graphs where the spacings are marked along X-axis and yield along Y-axis can be prepared as in Fig. 3 for each date of planting and the mean over all dates. Here a second degree polynomial can be fitted. Whether a smaller degree, namely, straight line will be adequate can be tested by analysis of variance. Whenever the 3 curves obtained for yield-date relationships at different spacings are mutually parallel, or the six curves obtained for yield-spacing relationships at different dates of plantings are mutually parallel can also be tested by further

analysis of variance of the interaction: Date × Spacing. This detailed analysis has been done in Tables VIIIA and VIIIB for grain and straw respectively.

line. This is why we found the 1 d. f. for date (1st degree) × spacing (1st degree) significant. The values of C show a tendency of decreasing magnitude with increase of spacing but except in two

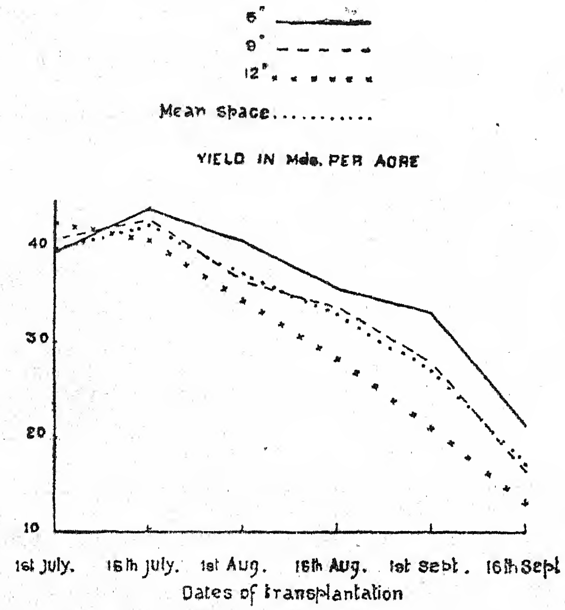

FIG. 2. Yield-date curves for different spacings

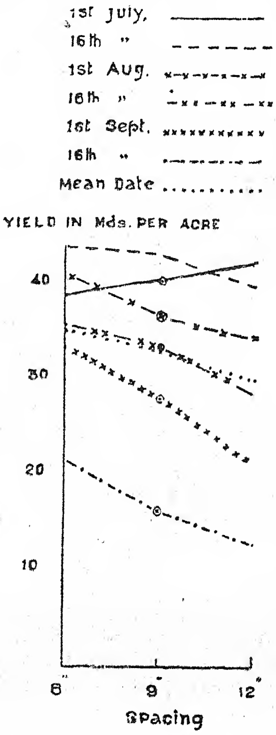

FIG. 3. Yield-spacing curves for different dates of transplanting

It will be seen that the yield-date relation can be adequately represented in the case of grain by a parabola of the form.

$$Y = a + bx + cx^2$$

where Y = yield, x = date of planting

In the case of straw the relation is adequately represented by a straight line. Similarly the yield-spacing relationship for both grain and straw are given by straight lines.

The detailed analysis of variance of the 10 d. f. for the interaction date × spacing of the grain yield reveals that the significance of this item is mainly due to 1 d. f. belonging to what we have called date (1st degree) × spacing (1st degree). Now the yield-date curve for any spacing 6 in., 9 in. or 12 in. is obtained by the formula

$$Y = A + B\left(x - \frac{7}{2}\right) + C\left\{\left(x - \frac{7}{2}\right)^2 - \frac{35}{12}\right\}$$
$$= a + bx + cx^2$$

The values of A, B, C obtained for each spacing is given in Table IX. We note that the three values of B increase in magnitude with increase in spacing and, if plotted, lie almost on a straight

years (1937-38 and 1940-41) this tendency is not significant as can be judged from the variance due to date (2nd degree) × spacing (1st degree).

The standard error of B and C have been calculated using the following formulae (see Appendix).

S. E. of B for each spacing $= \sqrt{\frac{2}{315}\left(\frac{\text{Error (II)} + 2\ \text{Error (IV)}}{3}\right)}$

S.E. of C for each spacing $= \sqrt{\frac{1}{336}\left(\frac{\text{Error (II)} + 2\ \text{Error (IV)}}{3}\right)}$

The appropriate test of significance of individual values of B or C is available in the Behrens and Fishers test for which Sukhatme [1938] has published tables. We have to enter this table with $n_1 = 10$, $n_2 = 72$ and $\tan^2\theta = \frac{\text{Error (II)}}{2\ \text{Error (IV)}}$. It can be immediately noted that at 12 in. spacing the values of C are not likely to be significant. The yield-date curve for 12 in. spacing must therefore be virtually taken as a straight line. Owing to the existence of a curvature in the yield-date curve within the range of dates studied, when the spacing

TABLE VIII A

Detailed analysis of variance—dates, Spacings, and Dates × Spacings (yield of grain in tolas)

	Degrees of freedom	Variance				
		1936-37	1937-38	1938-39	1939-40	1940-41
Dates—						
1st degree . .	1	1978736·36*	2748498·14*	1528888·90*	1515663·75*	2287334·66*
2nd degree . .	1	222659·08*	286976·25*	226300·28*	116616·04*	266868·78*
3rd degree . .	1	4537·53	8897·90	4850·01	108·75	4185·21
4th degree . .	1	19525·08	6876·19	41407·44	7224·30	67395·56
5th degree . .	1	9084·52	35328·34	12780·07	7158·50	92·66
Total .	5	426908·51**	617315·36**	362845·34**	329354·27**	525175·37**
Error (II) . . .	10	13999·35	24433·10	21490·15	18774·13	21195·87
Spacings—						
1st degree . .	1	70533·33*	270800·59*	167639·12*	174564·48*	156408·33*
2nd degree . .	1	1377·23	348·44	1853·78	6507·11	7·72
Total .	2	35955·28**	135574·52**	84746·45**	90535·80**	78208·03**
Dates × Spacings—						
Dates (1st deg.) × Spacings (1st deg.)	1	121284·96*	25749·54*	113050·98*	142167·82*	40278·87*
Dates (2nd deg.) × Spacings (1st deg.)	1	6751·34	60901·59*	7986·52	2936·00	16264·35*
Dates (1st deg.) × Spacings (2nd deg.)	1	1124·83	12089·31	5931·28	10·79	2097·85
Dates (2nd deg.) × Spacings (2nd deg.)	1	1333·04	13412·70	4104·77	343·36	0·005
Dates (deviation from 2nd degree curve) × Spacings	6	1975·46	6308·50	9484·91	6900·93	24154·39
Total .	10	14234·69**	15000·42**	18798·30**	18686·35**	20356·74**
Error (IV) . . .	72	3589·86	6982·82	6359·57	3202·01	5448·02

* Significant at 5 per cent level ** Significant at 1 per cent level

is at 6 in. and 9 in. we are in a position to determine the best date of planting which is given by

$$p = -\frac{1}{2}\left(\frac{B}{C} - 7\right)$$

The values of p have been worked out in Table IX for 6 in. and 9 in. spacing. The standard error of p is calculated from the approximate formula

$$\text{S.E. of } p = \frac{B}{2C}\sqrt{\left(\frac{\text{S.E. of } B}{B}\right)^2 + \left(\frac{\text{S.E of } C}{C}\right)^2}$$

Fixing the values of p on the calendar we find that for 6 in. spacing, the best date of planting is invariably after the 2nd date used in the experiment, namely, 16 July. There is remarkable closeness in these optimum dates for various years. They are actually 21, 18, 21, 23, and 17 July in the respective years. The standard error of each estimated best date is about six days. For the 9 in. spacing the best date is between 1 July and 16 July except for one year, 1938-39 when it falls on 27 July. In the other years the dates are 1, 10, 2 and 8 July for 1936-37 to 1940-41. The standard error of these dates are higher than for the 6 in. spacing, and vary between 9 and 17 days. We cannot therefore make a very rigid location of the best date of planting. But the procedure followed in the statistical treatment of the data indicates lines of re-planning the experiment to achieve the purpose of fixing the best date.

In the case of yield of straw, Table IVB shows a downward linear trend with advancing date of planting and also with increase of spacing. There is no interaction between the two linear trends. We can only say that the earlier the date of planting the greater the yield of straw and that the wider the spacing between the plants the smaller the yield.

ACKNOWLEDGEMENT

In conclusion our thanks are due to Mr S. Raja Rao of the Calcutta Statistical Laboratory for checking some of the numerical work.

Table VIII B

Detailed analysis of variance—Dates, Spacings, and Dates × Spacings (yield of straw in tolas)

	Degrees of freedom	Variance				
		1936-37	1937-38	1938-39	1939-40	1940-41
Dates—						
1st degree	1	15620165·29**	25519611·60**	19089472·50**	11286805·83**	21040814·76**
2nd degree	1	95148·19	41229·67	741362·44	1098548·16	1107501·73
3rd degree	1	79691·85	17256·99	93746·71	179124·49	27936·30
4th degree	1	2235·45	1503127·12	35150·83	144309·56	104351·75
5th degree	1	1749·34	12793·50	632616·37	86256·84	32114·88
Total	5	3159798·02**	5418854·55**	4120980·15**	2558610·52**	4462671·27**
Error (II)	10	46059·97	532764·04	347809·60	218019·97	294997·59
Spacings—						
1st degree	1	1707559·07**	4740985·04**	1274008·33**	1267500·00**	1339562·81**
2nd degree	1	194089·20**	1858·57	1038·27	1074·38	59536·00
Total	2	950824·23**	2371421·80**	637523·30**	634277·94**	698418·74**
Dates × Spacings—						
Dates (1st deg.) × Spacings (1st deg.)	1	45240·08	52535·31	49406·43	40346·75	77534·49*
Dates (2nd deg.) × Spacings (1st deg.)	1	529·78	63259·69	16933·59	9·52	35071·11
Dates (1st deg.) × Spacings (2nd deg.)	1	15280·42	15288·47	16594·24	2986·69	78811·53*
Dates (2nd deg.) × Spacings (2nd deg.)	1	10664·03	103467·57	89688·91	21302·67	126096·79**
Dates (deviation from 2nd degree curve) × Spacings	6	10343·86	85716·74	24757·20	6736·17	55063·76
Total	10	13377·75	74885·15	27116·64	10506·27	64789·65*
Error (IV)	72	15857·56	51618·28	61076·69	12959·88	15868·47

* Significant at 5 per cent level   ** Significant at 1 per cent level

Table IX

Calculation of best date of planting

Year	Spacing	A	B	S. E. of B	C	S. E. of C	a	b	$p=\frac{7}{2}-\frac{B}{C}$	S. E. of p	Best date of planting
1936-37	6 in.	469·89	—44·00	6·69	—18·85	4·58	448·06	87·92	2·33	0·33	21 July
	9 in.	438·15	—66·90		—13·24		548·87	25·76	0·97	0·92	1 July
	12 in.	418·78	—83·24		—12·51		593·45	4·29	0·17	1·27	
1937-38	6 in.	565·81	—63·65	9·01	—23·81	6·17	566·41	103·04	2·16	0·40	18 July
	9 in.	518·85	—83·42		—22·30		605·27	70·03	1·61	0·57	10 July
	12 in.	465·67	—81·73		—4·74		707·20	—48·32	—5·06	11·21	
1938-39	6 in.	479·26	—40·44	8·51	—17·30	5·83	459·40	80·66	2·33	0·47	21 July
	9 in.	447·04	—51·87		—18·18		459·40	75·07	2·70	1·11	27 July
	12 in.	400·46	—78·33		—10·41		577·54	—5·49	—0·26	2·14	
1939-40	6 in.	443·24	—34·89	7·30	—17·07	4·99	406·10	84·59	2·48	0·37	23 July
	9 in.	416·48	—56·51		—11·66		505·43	25·14	1·08	1·09	2 July
	12 in.	362·83	—74·04		—3·79		598·33	—50·88	—6·72	—12·90	
1940-41	6 in.	430·19	—59·76	8·24	—21·19	5·64	441·56	88·59	2·09	0·42	17 July
	9 in.	391·67	—66·60		—16·27		472·97	47·28	1·45	0·76	8 July
	12 in.	354·07	—82·37		—11·35		536·46	—2·90	—0·13	—1·85	

SUMMARY

The results of a complex cultural experiment with three winter varieties of rice conducted at the Dacca Farm in five successive seasons from 1936-37 to 1940-41 have been studied with respect to the best date of planting and best spacing between plants. It has been found that for yield of grain all the varieties gave similar results consistently over the five years with regard to the other factors namely, dates of planting and spacings. The best date of planting differs for the three spacings. Thus with 6 in. spacing the best date of planting is in the second half of July and with 9 in. spacing it is in the first half. The 12 in. spacing gives poor results and the best date could not be estimated with reasonable accuracy. As regards yield of straw the optimum is reached with the smallest spacing and the earliest date of planting.

Though there was wide variation in mean yields of plots for the five seasons there was no interaction between the experimental factors and seasons which is a clear indication that the results obtained about influence of dates of planting and spacings have a wide inductive basis.

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APPENDIX

Calculation of standard errors of orthogonal coefficients of the yield-date parabolic curve

If the mean yields per plot in any particular year and for a given spacing are $y_1, y_2, \ldots\ldots y_6$ for the six dates of planting, the linear and quadratic orthogonal coefficients of the yield-date curve for that spacing are given by [Fisher and Yates, 1943]

$$B=\tfrac{1}{35}\ [5\ (y_6-y_1)+3(y_5-y_2)+(y_4-y_3)] \qquad (1)$$

$$C=\tfrac{1}{56}\ [5\ (y_1+y_6)-(y_2+y_5)-4\ (y_3+y_4)] \qquad (2)$$

The variances of B and C in terms of variance of a single difference between two values of y are given by

$$V(B)=(\tfrac{1}{35})^2\ (5^2+3^2+1^2)\ V\ (y_i-y_j) = 1/35\ V\ (y_i-y_j) \qquad (3)$$

$$V\ (C)=(1/56)^2\ (5^2+1^2+4^2)\ V\ (y_i-y_j) = 3/224\ V\ (y_i-y_j) \qquad (4)$$

In terms of symbols of treatment combinations, namely $v_1\ v_2,\ v_3$ for the varieties; $d_1,\ d_2,\ \ldots\ d_6$ for dates; and $s_1,\ s_2,\ s_3$ for spacing, the value of y_i-y_j for a given spacing, say s_1 is given by

$$y_i-y_j=s_1\ (v_1+v_2+v_3)\ (d_i-d_j)/9 \qquad (5)$$

The right hand side of (5) can be expressed in terms of main effect of dates and the interaction between spacing and date. Thus—

$$27(y_i-y_j)=(s_1+s_2+s_3)\ (v_1+v_2+v_3)\ (d_i-d_j) + [(s_1-s_2)+(s_1-s_3)]\ (v_1+v_2+v_3)\ (d_i-d_j) \qquad (6)$$

Therefore

$$(27)^2\ V\ (y_i-y_j)=V\ [(s_1+s_2+s_3)\ (v_1+v_2+v_3)\ (d_i-d_j)] + V\ (2\ \ s_1-s_2-s_3)\ (v_1+v_2+v_3)\ (d_i-d_j)] \qquad (7)$$

Since 54 plots are involved in the main effect component with coefficients +1 and —1 for 27 each, the variance of that component is 54 times Error Variance (II).

In the interaction component the 54 plots involved have coefficients +2, —1 in 18 and 36 plots respectively, so that the variance of their component is $[18\ \ (2)^2\times 36\ \ (-1)^2]\times$ Error Variance (IV). Therefore $(27)^2\ V\ (y_i-y_j)=54$ Error (II) + 108 Error (IV)

$$\text{or } V(y_i-y_j)=\tfrac{2}{9}\ \left(\frac{\text{Error (II)}+2\ \text{Error(IV)}}{3}\right) \qquad (8)$$

Substituting (8) in (3) and (4) we get

$$V\ (B)=\tfrac{2}{315}\ \left(\frac{\text{Error (II)} + 2\ \text{Error (IV)}}{3}\right) \qquad (9)$$

$$V\ (C)=\tfrac{1}{336}\ \left(\frac{\text{Error (II)} +2\ \text{Error (IV)}}{3}\right) \qquad (10)$$

If B_1, B_2, B_3 stand for the linear coefficients of the yield date curve corresponding to spacings 6 in., 9 in., 12 in., variance of difference between any two B's has to be calculated as follows :—

Symbolically,

$$B_1-B_2=\left(\frac{1}{35\times 9}\right)[5\ (d_6-d_1)+3(d_5-d_2)+(d_4-d_3)]\ (s_1-s_2)\ (v_1+v_2+v_3) \qquad (11)$$

where any combination of the symbols d, s and v stands for the total of 3 replicated plots. The contrast involved in (11) consists of elementary contrasts of the type $(d_i-d_j)\ (s_1-s_2)$, that is, of the interaction between dates and spacings. Therefore,

$$V\ (B_1-B_2)=\left(\frac{1}{35\times 9}\right)^2\ \ [(5^2+3^2+1^2)\ \ 36]\times \textit{Error Variance}\ (IV)=\frac{4}{315}\times \textit{Error Variance}\ (IV) \qquad (12)$$

Similarly, if C_1, C_2, C_3 are the values of the quadratic coefficients of the yield-date curve corresponding to the spacings 6 in., 9 in., 12 in.

$$C_1-C_2=\frac{1}{56\times 9}[5\ \ (d_1+d_6)-(d_2+d_5)-4\ \ \ (d_3+d_4)]\ (s_1-s_2)(v_1+v_2+v_3) \qquad (13)$$

$$V\ \ (C_1-C_2)=\left(\frac{1}{56\times 9}\right)^2\ \ [(5^2+1^2+4^2)\ \ \ 36]\times \text{Error}\ \textit{Variance}\ \ (IV)=\ \frac{1}{168}\ \times \textit{Error Variance}\ (IV) \qquad (14)$$

To test whether B and C are significantly different from 0, the Behrens and Fisher test has to be employed. But the different values of B or of C can be compared by the usual t-test with 72 degrees of freedom.

PLANT QUARANTINE NOTIFICATIONS

Notification No. F. 16-3/43-A., dated the 28th March 1944 of the Government of India in the Department of Education, Health and Lands.

IN exercise of the powers conferred by sections 4A and 4D of this Destructive Insects and Pests Act, 1914 (II of 1914) the Central Government is pleased to prohibit, with effect from the 1st May 1944, the transport from the Province of Madras to any other Province of any of the articles specified in the First Schedule hereto annexed (being articles which are likely to carry the destructive insect known as Icerya Purchasi and thereby cause infection to crops) :—

(*a*) by letter or sample post, or by air ; or

(*b*) by road, except by such routes as may be specified by the Government of such other Province ; or

(*c*) by rail or inland steam vessel, unless the consignment is accompanied by a certificate in the form set out in the Second Schedule hereto annexed and signed by the Entomologist to Government, Madras, Coimbatore, or such other officer as the Director of Agriculture, Madras, may authorize in this behalf.

THE FIRST SCHEDULE

Articles to which this notification applies

1. The following plants (but not the fruits thereof) namely *Sophora glauca*, Silver Wattle (*Acacia-dealbeta*), Black Wattle (*Acacia decurrens* and *Acacia mollissima*), Australian blackwood (*Acacia melanoxylon*), Broom (*Cytisus scoparius*), *Ulex europaeus*, Potato creeper (*Solanum jasminoides*, *Solanum Seaforthianum* and other climbing *Solanums*), all citrus species including all types of orange, lime, lemon, pomeloe and grape-fruit plant, apples (all *pyrus* species), all Eucalyptus species including (*Eucalyptus spectabilis* and *Eucalyptus glauca*, *Rhodomyrtus tomentosa*, *Hypericum mysorense*, Dodonea/Bandedu (Telugu)/Aliar (*Dodonea viscosa*), *Berberis tinctoria*, Rose (*Rosa species*), *Gaultheria fragrantissima*, Raspberry, country pears, *Bougainvillea*, *Verbena*, Mangolia, Pepper, Tea, Casuarina.

2. The following plant materials, namely :— Buds, Cuttings, Scions, Grafts, bulbs, leaves (but not manufactured tea), seedlings, tubers, and rhisomes, of the plants specified in clause I.

3. Any articles used in packing or wrapping up any of the plants or plant materials mentioned above.

THE SECOND SCHEDULE

Form of certificate

This is to certify that the living plants/plant materials included in the consignment of which particulars are given below were thoroughly examined on (date) by (name and designation of official), a duly authorized official of the (name of the Department) and that the consignment including the packing covered by this certificate has been adequately treated and fumigated with hydrocyanic acid gas immediately prior to inspection and made free from Living *Icerya Purchasi*.

Date of examination and fumigation .. ..
....

Particulars of consignment..................

No. and description of packages..............

Distinguishing marks ....

Description of living plants or plant materials
....

Exported by ....

Name and address of the consignee............

Signature of certifying authority
Designation

The above certificate should be signed by the Entomologist to Government, Madras, Coimbatore, or such other officer as may be authorized by the Director of Agriculture, Madras, in this behalf.

Notice No. I of 1944

The following quarantine regulations and import restrictions have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council ot Agricultural Research, New Delhi, for loan.

Plant Quarantine Import Restrictions

1. *Republic of Maxico*—Exterior Quarantines No. 2 (Coffee) and No. 7 (Banana) Revised.

2. *French Equatorial Africa*—Importation of cotton, cottonseeds, and plants prohibited. Order No. 46 of January 9, 1943.

3. *Republic of Brazil*—Importation of Cotton Seedlings (Gossypium Spp.) prohibited.

GIPD—S3—9 IC of AR—16-12-44—600

ORIGINAL ARTICLES

FRACTIONATION OF SOIL PHOSPHORUS

III. THE ORGANIC PHOSPHORUS FRACTION

By M. O. Ghani, M.Sc., Ph.D.(Lond.), Department of Soil Science, Dacca University

(Received for publication on 14 April 1944)

In the two previous communications of this series [Ghani, 1943, 1; Ghani and Aleem, 1943] a method was outlined for the fractionation of soil phosphorus, and the chemical nature of the inorganic phosphorus fractions was elucidated. The organic phosphorus fraction was determined in the alkali extracts of soils, pretreated with N/2 acetic acid, by the bromine oxidation method of Dean [1938] modified by Ghani [1942]. The condition of alkali extraction with respect to the kind of alkali and its concentration, soil-solvent ratio, time and temperature of extraction and the technique of extraction were all defined there. The organic phosphorus determined in the alkali extracts was taken to be the total organic phosphorus of the soil. An attempt has been made here to determine the organic phosphorus of the soil by an independent method with a view to testing the validity of the fractionation method, so far as the determination of the organic phosphorus is concerned. The work was carried out at the Rothamsted Experimental Station, England, as a continuation of the work already reported by the author [Ghani, 1943, 1].

Determination of organic phosphorus by ignition method

It was observed by the earlier workers on soil phosphates that ignition of the soil increased solubility of soil phosphorus in dilute mineral acids. It was assumed that the effect of ignition was to destroy the organic phosphorus compounds and thus render the phosphates soluble in acid, without affecting the solubility of inorganic phosphates. A method for determination of organic phosphorus in soil was based on this assumption. A portion of the soil was ignited, extracted with mineral acid of certain strength and phosphoric acid estimated in the extract. From this was subtracted the amount of phosphorus extracted from the ignited soil by the same solvent under identical conditions of extraction and the result was taken to represent the organic phosphorus of the soil. Stewart [1910] found that ignition method gave results higher than the ammonia extraction method and Fraps [1911] contended that it includes some of the mineral phosphates which are rendered more soluble in acid by ignition. Peterson [1912] refuted the criticism of Fraps and showed that the solubility of the mineral phosphates of the soil did not increase by heating. On the face of such conflicting evidence, no further use of the method appears to have been made till comparatively recently.

Odynisky [1936] adopted the ignition method for determining the organic phosphorus content of five Alberta soils. The extractant was 2 N sulphuric acid and ignition was carried out at 600°C. for an hour. He extracted both the fresh and ignited soil repeatedly with the acid and found that four extractions were needed to remove the soluble phosphorus. The soluble phosphorus in the extracts after the first one was found to be similar in amount for fresh and ignited soils and thus a single extraction was thought to be sufficient to determine the organic phosphorus by difference. Odynisky's method has been used here in the determination of organic phosphorus of the same eight soils as were used in the alkali method.

Method of determination

Two one-gram samples of 20 mesh soil were weighed. One of the samples was ignited at 600°C. for one hour in an electric muffle. The ignited and unignited samples were then extracted with 200 c.c. of 2 N sulphuric acid by shaking for one hour and P_2O_5 in the filtered extracts was determined colorimetrically. Organic P_2O_5 was obtained by difference. As the extracts were too acidic for a direct colorimetric determination of phosphorus, they were adjusted to pH 3 with ammonia. The ammonium salts formed on neutralization interfered with the development and stability of the molybdenum blue colour. To obviate the error thus introduced an equal volume of 2 N sulphuric acid was added to the standard which was then neutralized with ammonia as before. This was not necessary when the extract was highly phosphatic and when only a small aliquot was required for the determination.

The results are shown in Table I and for comparison the organic phosphorus determined by the alkali method [Ghani, 1943, 1] is also presented in the same table.

TABLE I

Organic phosphorus by ignition method

(Mg. P_2O_5 per 100 gm. of soil)

Soil	Acid-soluble P_2O_5 in fresh soil	Acid-soluble P_2O_5 in ignited soil	Organic P_2O_5 by difference	Organic P_2O_5 by alkali method
A 1441, Rothamsted	51	118	67	68
A 2242, Woburn	98	144	46	42
A 3457, Saxmundham	42	80	38	37
A 2328, Broadbalk	133	176	43	45
A 3328, Carbello	80	230	150	140
A 3769, Flatterton	118	365	247	244
A 3246-7, Peterboro	307	444	137	108
A 3560-1, Littleport	96	221	125	84

It will be seen from Table I that in six out of the eight soils, the two methods give fairly agreeable results. It is only with the two heavy black fen soils from Peterborough and Littleport that the results do not agree and the discrepancy is more marked in the latter soil. These two soils are highly acid, their carbon content and clay content are also highest of the lot. The organic carbon content of the Peterborough and Littleport soils are 16·8 and 29·2 per cent respectively and they contain 34·0 and 45·5 per cent clay respectively. A fractionation study of the six soils reported previously also showed that these two soils contain high amounts of iron and aluminium phosphates. The higher values of organic phosphorus obtained by the ignition method were at first supposed to be due to some of the inorganic phosphates being included in it through its increased solubility by ignition as was pointed out by Fraps. To see whether ignition at lower temperatures would materially affect the acid-soluble phosphorus, ignition was carried out at 350°, 400° and 500°C. To ensure complete destruction of organic matter, the soils were kept at 400° and 350°C. for 2 hours and 3 hours respectively. The results are given in Table II which shows that temperature of ignition has practically no effect on the sulphuric acid soluble phosphorus and, therefore, if any change in the solubility of the inorganic phosphates has taken place it must have occurred at the lowest temperature.

TABLE II

Effect of temperature of ignition on phosphorus soluble in 2 N sulphuric acid

(Mg. P_2O_5 per 100 gm. of soil)

Temperature	600°C.	500°C.	400°C.	350°C.
Time	1 hour	1 hour	2 hours	3 hours
A 3246-7	444	444	448	452
A 3560-1	221	218	220	220

EFFECT OF IGNITION ON THE ACID-SOLUBILITY OF PHOSPHORUS COMPOUNDS

Doughty [1935] determined the effect of heat on the solubility of phosphorus compounds of iron and aluminium in 0·002 N sulphuric acid. He found that ignition of ferric phosphate at 800°C. decreased the soluble phosphorus from 0·138 mg. to 0·072 mg. (at 600°C., 0·116 mg.) and in the case of aluminium phosphate ignition at 800°C. decreased the soluble phosphorous from 0·90 mg. to 0·012 mg. (at 600°C., 0·03 mg.). A sample of apatite gave no increase of soluble phosphorus when heated to 800°C., natural hydrated iron oxides containing some basic ferric phosphate showed a large increase in soluble phosphorus when heated under the same condition.

As the acid used in this work is much stronger, the effect of ignition on the solubility of normal and basic iron phosphates in 2 N sulphuric acid was determined. Where the whole of the phosphorus did not dissolve in one extraction, extraction of the residue was repeated with the acid. The ignition of the substances was carried out at 600°C. for one hour. The data are given in Table III.

TABLE III

Phosphorus dissolved by 2 N H_2SO_4 from fresh and ignited iron phosphate

(Per cent of P_2O_5 used)

Material		Fresh	Ignited
Normal iron phosphate	1st extract	100	50·0
	2nd extract	..	34·4
	3rd extract	..	3·2
	Total	100	87·6
Basic iron phosphate	1st extract	100	40·4
	2nd extract	..	57·0
	3rd extract	..	2·0
	Total	100	99·4

It will be seen from Table III that both normal and basic iron phosphates are completely soluble in 2N sulphuric acid. Ignition considerably decreased the solubility of both the substances. Basic iron phosphate, when ignited, required three extractions to dissolve the whole of its phosphorus, whereas in the normal iron phosphate, only about 88 per cent of its phosphorus was dissolved by three extractions. With basic iron phosphate, the

second extraction dissolved more phosphorus than the first one which suggests that the decreased solubility caused by ignition may be due to physical changes such as fusion of the particles into hard lumps. It will also appear, that simple phosphorus compounds behave differently on ignition from the natural phosphatic minerals; in the former case solubility is decreased whereas in the latter solubility is increased [Fraps, 1911].

The inorganic phosphates of the soil are present not only in the form of minerals but also as various colloidal complexes containing simple precipitated phosphorus compounds. It is quite likely that the increased solubility of the phosphorus in minerals such as wavellite, variscite and triplite tested by Fraps, is due to an increase in the surface exposed owing to disintegration by heat. On the other hand, with precipitated phosphates fusion will reduce the surface. In a complex material like soil which contains many kinds of mineral particles in different stages of disintegration and varying quantities of colloidal materials, it is scarcely possible to decide which process will predominate.

Use of acetic acid as a solvent

One way of getting rid of the contention that organic phosphorus determined by the ignition method includes some inorganic phosphorus is to choose an acid for extraction which would have no solvent action on the minerals. It is known that dilute acetic acid extracts from soil only the easily soluble phosphates and that it has no appreciable solvent action upon such minerals as wavellite and dufrenite, and other naturally occurring phosphates of iron and aluminium. Thus, if dilute acetic acid is substituted for 2 N sulphuric acid in the ignition method, the possibility of some inorganic phosphorus being included in the organic phosphorus thus determined may be eliminated. But in the absence of sufficient base in the soil, some of the phosphorus liberated by the destruction of organic matter may combine with the free iron and aluminium, forming iron and aluminium phosphates which are insoluble in acetic acid. To reduce these secondary reactions to a minimum, it was proposed to ignite the soil with chemically pure magnesium oxide and then to extract the ignited sample with N/2 acetic acid. The phosphorus liberated from organic compounds will combine with the base to form magnesium phosphate which is soluble in acetic acid. Again, inorganic soil colloids fix phosphorus from acetic acid solution, and the fixing power of a soil is considerably changed by ignition. Phosphorus will be fixed from acetic acid extract of both fresh and ignited samples during the period of extraction, but in different amounts. If the fixing power of the soil is increased by ignition, the organic phosphorus obtained by difference in the above method will be less than what it should be. To reduce this type of fixation, 8-hydroxy quinoline was added to the acetic acid. It has been shown by Ghani [1943, 2] that 8-hydroxy quinoline in acetic acid solution combines with the free sesquioxides present in the soil making them inactive. From these considerations the ignition method was modified as below.

A 5 per cent solution of 8-hydroxy quinoline in 2 N acetic acid was prepared. 5 c. c. of this solution and 195 c. c. of N/2 acetic acid was used for extracting one gram of soil. Two one-gram samples of the soil were mixed with 0·5 gm. of MgO and one was ignited at 600°C. for one hour in a muffle furnace. The ignited and the fresh samples were then extracted with 200 c. c. of the above 8-hydroxy quinoline-acetic acid solution by shaking for one hour in a rotatory shaker. The phosphorus in the extracts was determined colorimetrically and the organic phosphorus was obtained by difference. The results obtained with the fen soils are shown in Table IV. For comparison the results of acetic acid extraction without 8-hydroxy quinoline are also shown in the same table. The results show that the use of 8-hydroxy quinoline has increased the value of organic phosphorus in soil No. 3560-1 quite appreciably while in the other soil practically no change has been produced.

Table IV

Organic phosphorus by the modified ignition method

(Mg. P_2O_5 per 100 gm. of soil)

Soil	Extracted with acetic acid			Extracted with acetic acid and 8-hydroxy quinoline		
	Fresh	Ignited	Org. P_2O_5	Fresh	Ignited	Org. P_2O_5
A. 3246-7	28·0	160·0	132·0	32·0	163·2	131·2
A. 3560-1	24·8	102·4	77·6	34·4	140·8	106·4

The results obtained by the different methods are summarized and compared in Table V.

TABLE V

Organic phosphorus of fen soils determined by various methods

(Mg. P_2O_5 per 100 gm. of soil)

Soil	Ignition 2 N H_2SO_4	Ignition with MgO, N/2 acetic acid	Ignition with MgO, 8 (OH) quinoline-acetic acid	Alkali
A 3246-7 . .	137	132	131	108
A 3560-1 . .	125	78	106	84

It will be seen from Table V that in soil No. 3246-7 the organic phosphorus determined by the 8-hydroxy quinoline acetic acid method is nearly the same as that obtained by the sulphuric acid method, which indicates that the error due to increased solubility of mineral phosphates by ignition in the latter method is not serious in this soil. In the second soil, however, the values are quite appreciably reduced by the Modified method. The above modifications were introduced to explain the discrepancy of the results for the organic phosphorus as determined by the ignition and alkali method in the two fen soils. Comparing the modified ignition figures with the alkali figures it is found that the alkali figures are still lower. It was therefore thought that the low values of organic phosphorus by the alkali method might be due, at least in the fen soils, to inefficient acid pretreatment and incomplete extraction by the alkali. Schollenberger [1918] in comparing the efficiency of different acids as pretreating agents, found that in a highly organic soil acetic acid pretreatment was unsatisfactory for the determination of organic phosphorus by ammonia extraction. Lately, Wrenshall and Dyer [1941] showed that calcium phytate of soil is relatively insoluble in alkaline solution. If phytin or similar other organic phosphorus complexes of calcium happen to be present in large quantities in a soil, they will persist during alkali extraction unless the complexes are broken down and the calcium removed by a pretreatment. N/2 acetic acid used here may prove ineffective for this purpose and a stronger acid pretreatment may be necessary. Dyer and Wrenshall [1941] found that leaching with N HCl gave almost complete extraction of organic phosphorus by the subsequent alkali extraction. From this point of view the organic phosphorus was redetermined in the repeated alkali extracts after the soils were thoroughly extracted with normal hydrochloric acid instead of N/2 acetic acid. Determinations were made on all the eight soils.

ORGANIC PHOSPHORUS DETERMINED BY ALKALI METHOD AFTER PRETREATMENT WITH N HCl

One gram of soil was extracted with N hydrochloric acid each time with 100 c.c. of the solvent by shaking for two hours. The acid extracted soil was then repeatedly extracted with N/4 sodium hydroxide as usual and organic phosphorus determined in the extracts in the usual way. Unlike acetic acid, hydrochloric acid dissolved some organic phosphorus from the soil and hence the organic phosphorus in the acid extracts was also determined. As the acid extracts were a little coloured (especially in the organic soils) bromine oxidation had to be adopted for determining its organic phosphorus. It was also found necessary to remove the iron dissolved by the acid, in order that no interference might be caused in the colorimetric determination. The results are presented in Table VI. In the table the acid soluble organic phosphorus represent the organic phosphorus dissolved by two extractions with N hydrochloric acid and the alkali soluble part is the sum of the organic phosphorus of four successive extracts with N/4 sodium hydroxide. The total organic phosphorus obtained by this method has been compared in the same table with the corresponding figures using acetic acid as a pretreating agent, together with the ignition method figures.

TABTE VI

Organic phosphorus determined by alkali method after pretreatment with N HCl

(Mg. P_2O_5 per 100 gm. of soil)

Soil	A 1441	A 2242	A 3457	A 2328	A 3328	A 3769	A 3246-7	A 3560-1
N HCl	1·9	0·0	2·9	2·0	20·0	46·0	0·0	8·5
N/4 NaOH	64·6	33·7	30·8	39·2	110·5	194·9	119·5	96·4
Total .	66·5	33·7	33·7	41·2	130·5	240·9	119·5	104·9
Acetic acid pretreatment . .	68	42	37	45	140	244	108	84
Ignition method (2 N H_2SO_4) .	67	46	38	43	150	246	137	125
Ignition method (Hydroxy quinoline acetic acid)	..	..	..	..	..	..	131	106

It will be seen from Table VI that replacement of acetic acid by hydrochloric acid in the pretreatment has increased the values of organic phosphorus in both the fen soils but not by as much as will bring them to the level of the ignition figures ($H_2 SO_4$). In the remaining six soils, the nature of the pretreating agent had practically little effect upon the amount of organic phosphorus determined. With soil No. A 3560-1, the modified alkali method (HCl pretreated) gives results comparable with the modified ignition method (8-hydroxy quinoline acetic acid). The other soil too does not show widely divergent results. It would thus appear that the alkali method and the ignition method can be reliably used in a majority of soils. Only the highly organic soils appear to give somewhat lower values by the ordinary alkali method and somewhat higher ones by the ordinary ignition method. The ignition method gives better results when hydroxy quinoline acetic acid is used as an extractant instead of sulphuric acid. In such soils, the alkali method should also be modified by using a stronger acid for pretreatment.

It was next intended to see how far the hydrogen peroxide oxidation method can be used for the determination of the organic phosphorus of the soil.

Determination of organic phosphorus by hydrogen peroxide oxidation method

This method is similar in principle to the ignition method; the organic matter of the soil is oxidized with hydrogen peroxide instead of by ignition. Peterson [1912] found that nearly 90 per cent of the organic matter was removed by hydrogen peroxide and that the phosphorus extracted by 0·2 N nitric acid was greatly increased by such treatments. Hydrogen peroxide oxidation always gave a greater increase in acid-soluble phosphorus than did ignition. Dushechkin and Gorodinsky [1936] used hydrogen peroxide as an oxidizing agent in separating the organic form of phosphorus from the mineral one. The soil was previously treated with 0·05 N hydrochloric acid in order to remove the most easily soluble part of the mineral phosphoric acid. The acid treated soil was then digested with 30 per cent perhydrol till apparent disappearence of humus. The oxidized soil was then washed with 0·05 N hydrochloric acid till the reaction for phosphoric acid disappeared. The phosphoric acid determined in the leachate was supposed to be in organic form. Dickman and De Turk [1938] made a further study of the hydrogen peroxide method and determined the organic phosphorus content of ten soils by this method. Phosphorus was extracted from the soil with 0·2 N sulphuric acid, and the difference between the phosphorus contents of the extracts of the oxidized and unoxidized soil was taken as a measure of the organic phosphorus.

In the method adopted here, 0·05 N hydrochloric acid has been used as an extractant.

Method of determination

One gram of soil was weighed into a 100 c.c. Erlenmeyer flask and 10 c.c. of 90 to 100 volume hydrogen peroxide (phosphorus free) added to the soil. After the reaction ceased, the flask was heated on a sand bath with occasional shaking, care being taken to prevent loss by frothing by removing the flask from the sand bath occasionally. Hydrogen peroxide was then added by small portions (5 c.c.) every 10 min. until apparent disappearance of the organic matter. The contents of the flask were evaporated to a thick paste, washed with 0·05 N hydrochloric acid into a shaking bottle and diluted with the same acid up to the 250 c.c. mark. The bottle was shaken in a mechanical shaker for two hours, filtered and P_2O_5 determined colorimetrically on an aliquot of the filtrate. Before the colorimetric determinations were done traces of hydrogen peroxide in the extract were removed by evaporating the latter to dryness.

Another one gram sample of the soil was extracted with 250 c.c. of 0·05 N hydrochloric acid by shaking for two hours and P_2O_5 determined in the filtrate. Organic phosphorus was obtained by difference.

The results for the eight soils under study, obtained by the above method, are shown in Table VII and compared with those obtained by the ignition method.

TABLE VII

Organic phosphorus by hydrogen peroxide oxidation method

(Mg. P_2O_5 per 100 gm. of soil)

Soil	Acid-soluble P_2O_5 in fresh soil	Acid-soluble P_2O_5 in oxidized soil	Organic P_2O_5 by difference	Organic P_2O_5 by ignition method
A 1441	7	40	33	67
A 2242	15	42	27	46
A 3457	9	23	14	38
A 2328	31	75	44	43
A 3328	8	132	124	150
A 3769	30	305	275	246
A 3246-7	61	370	309	137
A 3560-1	52	212	160	125

It will be seen from Table VII that, except in soil No. A 2328, the two methods give discordant results for organic phosphorus. With the three

highly organic soils (A 3769, A 3246-7 and A 3560-1) the hydrogen peroxide method gives much higher values than the ignition method, while with the remaining four soils the converse is true.

Discussion of the hydrogen peroxide method

In adopting this method for the determination of organic phosphorus in soils, the following assumptions were made.

(1) Hydrogen peroxide decomposes the organic matter completely and releases all the organic phosphorus in an acid soluble form.

(2) Hydrogen peroxide oxidation has no effect on the solubility of the inorganic phosphates.

(3) None of the liberated phosphorus is fixed by the soil.

As regards the first assumption, there is no definite evidence that hydrogen peroxide destroys the organic matter completely. Peterson [1912] investigated this point and found that removal of 60 per cent of organic matter gave as much soluble phosphorus as the removal of 80 per cent. From this evidence he concluded that 'it seems reasonable to believe that removal of the entire amount of organic matter will not increase the solubility of the phosphoric acid above that already obtained.' But this may not be true for all types of soils. In the soils used here the lower organic phosphorus values (as compared with the ignition method) were obtained from the soils which are low in organic matter, while those high in organic matter gave higher values. So it does not seem that the discrepancy is due to incomplete oxidation of the organic matter.

As regards the second assumption, it is quite probable that some of the organic phosphates will be protected from the solvent by the organic matter before oxidation. Peterson [1912] studied the effect of different degrees of oxidation on the solubility of phosphorus, iron, aluminium, calcium and manganese. He found that the increase in the soluble iron and aluminium was roughly parallel to the increase in soluble phosphorus while the calcium and manganese remained constant in solubility. This led him to believe that iron and aluminium were not combined with the phosphorus in a single organic molecule but that some of the phosphates of iron and aluminium were merely protected from the solution before oxidation by the organic matter and were dissolved by the acid when the organic matter was decomposed. It seems that the higher values of organic phosphorus of the three soils are due to this reason. They are highly organic and contain a large amount of iron phosphates as determined by alkali extraction. Soil No. A. 3246-7 which shows the greatest discrepancy contains the highest amount of iron phosphate [Ghani 1943, 1].

As regards the third point, Dickman and De Turk [1938] found that some of the phosphorus liberated during the oxidation was fixed in a form which was insoluble in 0·002 N sulphuric acid. Even with 0·2 N sulphuric acid, reliable results could not be obtained by them and it was found that appreciable fixation of the liberated phosphorus took place, especially in soils low in organic matter and high in active iron and aluminium. They suggested a correction factor (based on the fixing power of the soil) to be applied to the organic phosphorus value as determined by hydrogen peroxide oxidation. They also suggested necessary modifications of the method to meet particular local conditions. It appears that the low values for organic phosphorus obtained in four soils are due to the fixation of the liberated phosphorus in a form not soluble in 0·05 N hydrochloric acid used in this work.

In determining organic phosphorus by hydrogen peroxide oxidation these sources of errors must be taken into account. To reduce these possibilities, the procedure was slightly modified. The oxidation was carried out on the same sample as was extracted with acid. The preliminary extractions were repeated to deplete the soil of the easily soluble phosphorus. This would remove, to a certain extent, the possibility of some inorganic phosphorus being included in the final extract, particularly in the three organic soils from which the first acid extraction dissolved quite a high amount of phosphorus. The oxidized soil was also repeatedly extracted to dissolve the fixed phosphorus as far as possible.

One gram of soil was repeatedly extracted with 0·05 N hydrochloric acid. Three extractions were needed to bring down the soluble phosphorus to a small quantity. The residual soil was washed off the bottle with water into a conical flask and the water evaporated off. The oxidation with hydrogen peroxide was carried out as before. The contents of the flask were then washed off into a shaking bottle with 0·05 N hydrochloric acid and extracted as before. The extraction was repeated thrice, and phosphorus determined in the extract.

The data obtained are presented in Table VIII. Comparing Table VII with Table VIII it will be seen that the modified procedure gave lower values for the three organic soils while in the remaining five there was a slight increase. However, on comparing with the organic phosphorus values by the ignition and alkali method (Table VI) it will be found that hydrogen peroxide oxidation gave much lower values in soils A. 1441, A. 2242, A. 3457 and A. 3328, higher values in soils A. 3246-7 and A. 3560-1 and comparable values in soils A. 2328 and A. 3769. From the conflicting results obtained here with different types of soil

it may reasonably be said that hydrogen peroxide oxidation method for the determination of the organic phosphorus in its present stage, cannot be universally applied to obtain reliable results and that the conditions for extraction and oxidation need thorough investigation as regards fixation and other factors discussed here.

TABLE VIII

Organic P_2O_5 by H_2O_2 oxidation (repeated extraction with 0·05 N HCl)

(Mg. P_2O_5 per 100 gm. of soil)

Soil	1st Extract	2nd Extract	3rd Extract	Total organic P_2O_5
A. 1441 . .	20	10	8	38
A. 2242 . .	16	9	7	32
A. 3457 . .	10	4	3	17
A. 2328 . .	30	10	7	47
A. 3328 . .	104	14	10	128
A. 3769 . .	198	27	17	242
A. 3246-7 . .	208	26	14	248
A. 3560-1 . .	131	7	3	141

SUMMARY

With a view to testing the validity of the fractionation method in determining the organic phosphorus of the soil, an independent method based on ignition has been used for the determination of the fraction.

The ignition method gave results for organic phosphorus which agreed fairly well with those by the alkali method except in the two fen soils. The causes of this discrepancy were examined and the methods modified accordingly.

The temperature of ignition when varied from 350° to 600°C. did not effect the results for organic phosphorus. Ignition considerably reduced the solubility of basic and normal iron phosphates in 2 N sulphuric acid.

To obviate the possibility of error due to change in acid-solubility of the inorganic phosphorus compounds and phosphatic minerals caused by ignition, N/2 acetic acid was substituted for 2 N sulphuric acid as an extractant. Also to prevent any possible fixation of phosphorus from the acetic acid extract, 8-hydroxy quinoline was introduced in the extracting acid and the ignition of the soil was carried out in presence of magnesium oxide. The ignition method thus modified gave lower values than before in both the soils, though they were still higher in comparison with the alkali method figures.

The alkali extraction method was also modified with respect to the pretreating acid. Pretreatment of the soil with N HCl instead of with N/2 acetic acid, increased the values for organic phosphorus in the two fen soils; in the remaining six soils nature of the pretreating agent had a slight effect on the amount of organic phosphorus determined. The modified alkali method gave results comparable with the modified ignition method in the two fen soils.

From the work reported, it appears that both the methods can be used reliably in the majority of soils. Only in the case of a special type of highly organic fen soils, the methods need modification.

The validity of using hydrogen peroxide oxidation method for the determination of organic phosphorus was next examined. It was found that from various points of view this method cannot be universally applied to obtain reliable results.

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THE MANURIAL VALUE OF DIFFERENT MINERAL PHOSPHATES IN CALCAREOUS SOILS

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(With one text-figure)

Soils in the Indo-Gangetic alluvium around Pusa in Bihar contain 30 to 40 per cent of calcium carbonate. This is likely to enter into combination with many of the constituents of fertilizers used in ordinary farm practice, rendering them insoluble and consequently perhaps unavailable to plants. This untoward feature has baffled many attempts in the past to evolve a successful method of manuring these calcareous soils, especially with regard to their supply of phosphorus. Superphosphate is the phosphatic fertilizer commonly recommended for such soils.

Experience has shown that the beneficial action of superphosphate on calcareous soils is not always appreciable, although good crop yields are usually obtained when applied in conjunction with organic manures as reported by Hutchinson [1923]. Commercial super contains 50 to 60 per cent of gypsum. Studies made by the author [Das, 1933] to determine the effect of gypsum on the cropping value of calcareous soils, showed that it exerted no beneficial influence, but often depressed the yield. The presence of gypsum therefore may account in some measure for the uncertain and disappointing results often obtained with commercial super in calcareous soils.

Harrison and Das [1921] have shown that the action of super on calcareous soils is very localized; the major portion of its P_2O_5 is retained in the top layers with the formation of dicalcium phosphate. The latter then becomes slowly converted into insoluble tricalcium phosphate on reacting with excess of calcium carbonate already present. Consequently, the application of super to these soils has a very restricted effect and probably much less efficiency than equivalent amounts applied to non-calcareous soils.

On the other hand, it was shown by the authors [Harrison and Das, 1921] that, by using dressings of soluble phosphates like those of sodium which have little or no action with calcium carbonate, in place of super, on calcareous as well as non-calcareous soils, a much more uniform distribution of P_2O_5 throughout the soil can be attained. Provided that these phosphates are suitable as plant food, this wider distribution can only result in a wider and deeper root action and better cropping in these soils. It was therefore considered desirable to test how far these soluble sodium and similar phosphates could be successfully utilized in calcareous soils as phosphatic fertilizers.

In order to do this, some soluble phosphates such as meta- and pyro-phosphates of sodium were prepared as described below; these contained 67·20 and 51·98 per cent of P_2O_5 respectively, the theoretical amounts being 69·61 and 53·43 per cent.

Sodium hexametaphosphate $(NaPO_3)_6$. To a solution of common sodium phosphate Na_2HPO_4, $12HO_2$ add the requisite quantity of phosphoric acid H_3PO_4 to form sodium dihydrogen phosphate NaH_2PO_4. The latter is heated to complete fusion. The melted mass must be quickly cooled to avoid the formation of trimetaphosphate $(NaPO_3)_3$. The product is a vitreous mass, soluble in water and slightly acid in reaction.

Sodium pyrophosphate $Na_4P_2O_7$. It is obtained in the anhydrous state as a colourless glassy mass by igniting common sodium phosphate and quickly cooling the ignited mass. It dissolves in water and is alkaline in reaction.

Besides, sodium phosphate Na_2HPO_4, $12H_2O$, dicalcium phosphate $CaHPO_4$, $2H_3O$, and tricalcium phosphate $Ca_3(PO_4)_2$ were used in pot experiments. Parallel experiments with super were also carried out for comparison. In pot experiments monocalcium phosphate $CaH_4(PO_4)_2$ H_2O which is devoid of gypsum, but contains the chief phsophatic constituent of commercial super, was used in place of super.

A sample of Pusa soil containing 33 per cent of calcium carbonate was collected from a fallow plot for pot experiments in 1919. Four pots of almost similar dimensions, e.g. 12 in. diameter by 22·5 to 24·0 in. high formed a group and received similar treatment. The pots contained 49 kilos of air-dry soil in each. Nitrogen was applied at the rate of 80 lb. per acre in the form of ammonium sulphate in order to prevent lack of nitrogen. Phosphates were added to the top three inches of soil as used in farm practice here at 80 lb. of P_2O_5 per acre, and the pots watered from the top to get the effect of different degrees of diffusion. *Ragi* (*Eleusine coracana*) was chosen as the *kharif* (summer) crop.

Although the weights of both grain and straw per pot were recorded saparately, only the yield

of grain is given in Table I. While examining the data, Fisher's [1932] analysis of variance was adopted.

TABLE I

The effect of different phosphates on the cropping value of a calcareous Pusa soil in pot experiments with ragi

Treatment	Replications				Mean yield in gm.	Per cent-age increase over control
	1	2	3	4		
Control . . .	18·2	16·3	16·7	17·6	17·2	...
Dicalcium phosphate	38·0	31·9	35·6	42·6	37·0	115·1
Monocalcium phosphate (super)	64·3	58·3	57·4	56·0	59·0	243·0
Sodium phosphate .	53·5	57·0	64·0	59·2	58·4	239·5
Sodium metaphosphate . . .	70·0	61·8	64·1	71·2	66·8	288·4
Sodium pyrophosphate . . .	70·4	68·6	75·4	71·8	71·6	316·3

Standard error of difference for comparison of mean yields by Fisher's [1932] analysis of variance = 2·62

Critical difference for P = 1 per cent = *7·54*

Ditto P = 4 per cent = *5·51*

The *ragi* crop, on account of its high salt tolerance, produced remarkably high yields in pots to which fertilizer salts were added. This is evident on examining the high percentage increase of yield over the control in the last column of Table I. It will be further noticed that the differences in mean yields of grain between control and every other treatment are significant at one per cent level. Such significant relationships have been obtained between other treatments too with the exception of those between monocalcium phosphate and sodium phosphate as well as between sodium meta- and pyro-phosphates. Although all the phosphates have given significantly better yields than the control, sodium meta- and pyro-phosphates give higher crop returns than the other phosphates.

Monocalcium phosphate which was used in place of commercial superphosphate in order to eliminate the deleterious influence of gypsum contained in super has produced results comparable with phosphates of sodium. When the efficiency of other phosphates over monocalcium phosphate is compared, only meta- and pyro-phosphates give significantly better yields than monocalcium phosphate. The effect of sodium phosphate is uncertain, and that of dicalcium phosphate is negative.

In the winter of 1919 these pot experiments were repeated, but without nitrogen. Oats were chosen as the *rabi* (winter) crop. The yield of grain of individual pots is set forth in Table II.

TABLE II

The effect of different phosphates on the cropping value of a calcareous Pusa soil in pot experiments with oats

Treatment	Replications				Mean yield in gm.	Percent-age in-crease over control
	1	2	3	4		
Control . . .	27·0	26·8	29·2	26·0	27·3	...
Monocalcium phosphate (super)	36·0	34·2	33·2	35·1	34·6	26·8
Dicalcium phosphate	34·7	29·8	36·1	35·5	34·0	24·5
Tricalcium phosphate	33·0	34·6	34·0	33·6	33·8	23·8
Sodium phosphate .	30·4	32·6	33·4	35·3	32·9	20·5
Sodium metaphosphate . .	37·2	34·0	39·2	39·5	37·5	37·4
Sodium pyrophosphate . .	37·7	34·5	39·9	36·8	37·2	36·3

Standard error of difference for comparison of mean yields by Fisher's [1932] analysis of variance = 1·403

Critical difference for P = 1 per cent = *3·97*

Ditto P = 5 per cent = *29·1*

Ditto P = 10 per cent = *24·2*

The differences in mean yields of oats between control and every other treatment are similar to those in the preceding pot experiments with *ragi*. Although all the phosphates have given significantly better yields than the control, sodium meta- and pyro-phosphates have again yielded higher crop returns than the remaining phosphates, thus confirming the conclusions emerging from the previous set of experiments with *ragi*.

Experiments on a field scale were next instituted during the monsoon of 1921 with *ragi*. Eighteen plots, each 2½ ft. wide and 42 ft. long, were laid out in three equal blocks having a margin of 2 ft. between them. Containing one plot of each of the six treatments distributed in a randomized manner, every block had thus six plots each with a border of one foot all around. During harvest, however, the crop of this border area was rejected in order to eliminate the border effect. Non-experimental margins were not however provided for each plot. *Ragi* seeds were sown in breadthwise line 6 in. apart and different phosphatic fertilizers were applied at the rate of 40 lb. of P_2O_5 per acre. The weights of grain are given according to blocks in Table III.

Sodium meta- and pyro-phosphates again produce markedly better yields than the other phosphates, and the results of these field experiments confirm the conclusions drawn from pot experiments. Moreover, from these cropping experiments the adverse effect of sodium ion resulting from the application of various sodium phosphates is not quite apparent on calcareous

TABLE III

The effect of different phosphates on calcareous Pusa soil in field experiments with ragi

Treatment	Replications			Mean yield in gm.	Percentage variation over control
	1	2	3		
Control	617	658	599	624·7	...
Superphosphate. . .	549	626	612	595·7	— 4·7
Tricalcium phosphate. .	699	599	658	652·0	+ 4·4
Sodium phosphate . .	735	671	717	707·7	+13·3
Sodium metaphosphate .	798	785	826	803·0	+28·5
Sodium pyrophosphate .	830	735	762	775·7	+24·2

Standard error of difference for comparison of mean yields by Fisher's [1932] analysis of variance = 32·7

Critical difference for P = 1 per cent = *103·6*
Ditto P = 5 per cent = *72·9*
Ditto P = 10 per cent = *59·3*

soils. This is perhaps due to their high content of calcium carbonate, which has no action on meta- and pyro-phosphates of sodium and reacts only slowly with sodium phosphate, as will be shown in the sequel.

On the other hand, superphosphate has given a lower yield than even the control, and tricalcium phosphate also does not show a significant increase. Thus, both the phosphates indicate their erratic effect on calcareous soils. In pot experiments where monocalcium phosphate was used which contains the chief phosphatic constituent of commercial superphosphate but not gypsum, its crop-depressing constituent, a significantly better crop yield than the control was secured. In these field tests, however, commercial superphosphate was used instead. This perhaps explains the disappointing result, which is the common experience in local agricultural practice, when super is used alone.

The pot and the field experiments have thus satisfactorily established the beneficial effect of the phosphates of sodium in calcareous soils. These results are very remarkable from the point of view of manuring calcareous soils with phosphatic fertilizers in order to supply their phosphatic needs.

Potassium and ammonium phosphates may also behave equally well in these soils. Commercial ammonium phosphates in their different grades of low nitrogen and high phosphate contents will, besides phosphates, supply nitrogen as well to which these calcareous soils readily respond. Work is in progress in this laboratory to manufacture similar phosphatic fertilizers from indigenous sources suitable for calcareous and other soils in India.

Having thus shown the beneficial action of several phosphates of sodium by pot and field experiments, it was next considered worthwhile to study the action of calcium carbonate normally present in calcareous soils on these phosphates. For this purpose, two series of 8 experiments in each group were carried out. One gram of pure precipitated calcium carbonate was shaken separately with 100 c.c. of sodium meta- and pyro-phosphate solutions containing 106·7 and 97·9 mg. of P_2O_5 respectively for 1, 3, 6, 16, 20, 24, 48, and 96 hours in end-over-end rotations in a mechanical shaker in a room which was not subjected to sudden changes of temperature. At the end of varying periods, the filtrates were examined for P_2O_5 content.

The concentration of P_2O_5 in the solutions remained constant both before and after shaking with calcium carbonate, showing the complete absence of interaction. Under the experimental conditions the possibility of the formation of compounds like calcium meta- and pyro-phosphate at ordinary laboratory temperature is rather remote, as they usually require a very high temperature for their preparation. Consequently, the absence of any reaction renders a more uniform distribution of these phosphates and ensures their better manurial value in calcareous soils.

The conclusion is therefore forced that the higher soluble phosphates of the type containing either PO_3 or P_2O_7 ions which have no reaction with calcium carbonate give the best results in calcareous soils by effectively supplying the phosphatic nutrition of plants, notwithstanding the presence of a large amount of calcium carbonate in them. This discovery opens up an altogether new line of attacking the important problem of manuring calcareous soils with phosphatic fertilizers of the meta- and pyro-type. Hitherto phosphatic manuring of soils all over the world has been mainly restricted to phosphatic fertilizers of the type having PO_4 ions in them.

Next the action of sodium phosphate, Na_2HPO_4, $12H_2O$ on calcium carbonate was studied. At ordinary laboratory temperature one gram of pure, precipitated calcium carbonate was shaken with 100 c.c. of a sodium phosphate solution containing 108·5 mg. of P_2O_5 for varying periods of time, at the end of which P_2O_5 concentration of the filtrates was determined. The difference between the P_2O_5 originally taken and that found in the filtrate after shaking gives the amount of P_2O_5 precipitated by calcium carbonate. The results are given in Table IV.

A slow, but progressive reaction takes place which proceeds in a well defined manner. It would appear that the reaction results in the formation of dicalcium phosphate in the first

TABLE IV

The reaction between sodium phosphate solution and calcium carbonate when shaken together for varying periods of time

Number of experiments	Time of shaking in hours (t)	Gm. P_2O_5 taken in solution	Gm. P_2O_5 in solution after shaking	Gm. P_2O_5 retained (y)	Per cent P_2O_5 retained by $CaCO_3$
1	6	0·1085	0·0935	0·0150	13·8
2	16	0·1085	0·0781	0·0304	28·0
3	24	0·1085	0·0719	0·0366	33·7
4	48	0·1085	0·0631	0·0454	40·9
5	96	0·1085	0·0518	0·0567	52·3
6	192	0·1085	0·0430	0·0655	60·4
7	384	0·1085	0·0362	0·0723	66·6
8	768	0·1085	0·0251	0·0834	76·9
Blank	768	0·1085	0·1085	*Nil*	No $CaCO_3$ added

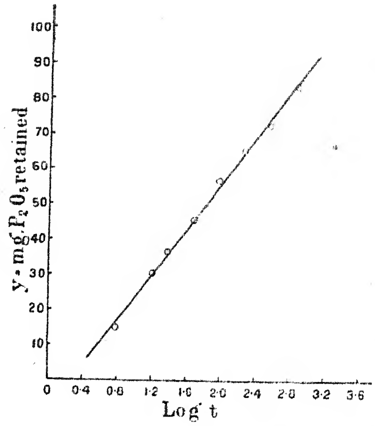

FIG. 1. Graph obtained by plotting the amounts of P_2O_5 retained by $CaCO_3$ against log of time.

TABLE V

A comparison of the calculated and the experimental values for the retention of P_2O_5 by $CaCO_3$

Number of experiments	t	y calculated	y found	Error
1	6	0·0165	0·0150	—0·0015
2	16	0·0300	0·0304	+0·0004
3	24	0·0357	0·0366	+0·0009
4	48	0·0454	0·0454	0·0000
5	96	0·0550	0·0567	+0·0017
6	192	0·0646	0·0655	+0·0009
7	384	0·0742	0·0723	—0·0019
8	768	0·0840	0·0834	—0·0006

instance, which, on reacting with excess of calcium carbonate already present, is slowly converted into tricalcium phosphate according to the following equations:

$$Na_2HPO_4 + CaCO_3 = CaHPO_2 + Na_2CO_3 \quad (1)$$

Dicalcium phosphate

$$2CaHPO_4 + CaCO_3 = Ca_3(PO_4)_4 + CO_2 + H_2O \quad (2)$$

Tricalcium phosphate

The solubility of dicalcium phosphate in water at the ordinary temperature is only 34 mg. of P_2O_5 per 100 c.c. and that of tricalcium phosphate is still less. The amount of P_2O_5 actually found in the solution after continuous shaking for 768 hours or 32 days is 25 mg. only per 100 c.c. which indicates that the reaction takes place in the manner shown above.

It is further noticed that the concentration of P_2O_5 in solution decreases with the period of time. The relationship between the amount of P_2O_5 retained (y) and the time (t) is a simple semi-logarithmic one as shown by plotting the values of y against the log of time (Fig. 1).

This relationship may be expressed by the general formula,

$$\log t = ay - k,$$

where y is the amount of P_2O_5 precipitated by $CaCO_3$ in time t, and a and k are constants. Employing the values of $a=31·22$, and $k=-0·264$, the calculated and the experimental vlaues of y are given in Table V which show close agreement among themselves.

From the relationship $\log t = ay - k$, it follows that under the experimental conditions $y = 0·032 \log t - 0·0085$, and hence the velocity of the reaction is $dy/dt = 0·032t^{-1}$, and the acceleration is $d^2y/dt^2 = 0·032t^{-2}$. The velocity of the reaction varies inversely as the time, and the acceleration is negative and is in inverse proportion to the square of time. The reaction is thus strongly retarded and can only reach completion at the end of a considerable period of time, which, when calculated from the experimental data, is found to be over six months. This conclusion is arrived at when the reacting bodies are in continuous and intimate contact but the retention of such soluble phosphates must proceed at a much slower rate under the conditions which obtain in the soil. This is due to the fact that carbonates in the soil are protected by soil colloids or locked up within other minerals. Consequently, they will not be so freely exposed to the action of sodium phosphate solution as the finely precipitated, pure calcium carbonate used in the experiments.

Therefore, soluble phosphates of the above type reacting slowly, or none at all with calcium carbonate, as in the case of sodium meta- and pyrophosphates, will have enough time during the growing season to get themselves easily distributed more uniformly into deeper layers, resulting in a wider and deeper root action and better cropping in calcareous soils.

Summary and conclusions

1. The effect of superphosphate on crop yields in calcareous soils is uncertain and erratic, although better results are usually obtained with it when applied in conjunction with heavy organic manures. This is due, among other factors, to the retention of water-soluble P_2O_5 in the upper layers of soils as insoluble calcium phosphates above the root-range of many crops and also to the deleterious influence of gypsum present in commercial super.

2. On the other hand, pyro- and meta-phosphates of sodium having no reaction at all with calcium carbonate, and di-sodium hydrogen phosphate which reacts only slowly with soil carbonates render a more even distribution of their P_2O_5 throughout the deeper layers of calcareous soils, resulting in a wider and deeper root action and better cropping. This has been satisfactorily demonstrated in calcareous soils both by pot and field experiments.

3. Higher soluble phosphates of the type of sodium meta-and pyro-phosphates containing respectively PO_3 and P_2O_7 ions which do not react at all with calcium carbonate, give the best crop results in calcareous soils. This suggests a new method of manuring calcareous soil types with suitable phosphatic fertilizers.

4. A slow, but progressive action takes place between sodium phosphate solution and the calcium carbonate normally present in calcareous soils. The relationship between the amount of P_2O_5 retained by soil carbonates and the time of reaction is a simple semi-logarithmic one, and can be expressed by the general equation,

$$\log t = ay - k,$$

where y is the amount of P_2O_5 retained in time t, and a and k are constants.

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ON THE BACTERIOPHAGE OF ROOT NODULE ORGANISMS

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Desai [1932] reported investigations on the nature of bacteriophages of root nodule organisms in which he evolved a method for the isolation and enhancement of the virulence of bacteriophages of certain leguminous plants. Following the method evolved by him the work on the bacteriophages of root nodule organisms proceeded on the following lines: (*i*) whether bacteriophage occurs in all legumes, (*ii*) if it occurs whether it is the same or different in different types of nodules, and if different, whether they form any basis for the classification of nodule bacteria, (*iii*) the relationship of bacteriophage to the formation or otherwise of nodules, and (*iv*) any practical utility of bacteriophage in nature.

A part of the work reported in this paper was carried out in 1932 and 1933 at Pusa in Bihar and the work was stopped in 1934 due to the great earthquake. The work was resumed at Delhi in 1940 when some of the conclusions arrived at Pusa had to be modified in the light of newer knowledge gained by working on legumes grown on different types of soil.

Work done at Pusa. Various leguminous plants were tested for the presence of bacteriolytic principle in their nodules. While some of them contained specific bacteriophage others did not show presence of any in them. The results are given in Table I. It will be seen from this table that berseem (*Trifolium alexandrianum*), Sweet pea (*Lathyrus odoratus*), Lucerne (*Medicago sativa*), Karao (*Pisum arvense*), Gram (*Cicer arietum*), Dolichos (*Dolichos Lablab*), contained bacteriophage in their root nodules, but cowpea (*Vigna catjang*), Sannhemp (*Crotalaria Juncia*), *Mung* (*Phaseolus radiatus*), Pea (*Pisum sativum*), Fennugreek (*Trigonella Foenum graecum*), Math (*Phaseolus aconitifolius*), Indigo (*Indigofera Tinctoria*), *Arhar* (*Cajanus indicus*) did not show presence of bacteriophage in their nodules. Attempts were made many times to isolate phage from these plants, but no success could be attained. It was then presumed that certain legumes have got phage in their nodules while others have not. These tentative conclusions have had to be modified when newer knowledge was gained by the work at Delhi. Karnal and Lyallpur.

Time of appearance of bacteriophage in the legumes. It will be noticed from Table I that the young plants did not indicate appearance of the bacteriophage in any types of plants experimented with. These results, so far as they go, are at variance with those of Laird [1932] who observed that bacteriophage might be isolated readily from young plants, and with difficulty or not at all from old ones.

Specificity of bacteriophages. Having obtained six different cultures of bacteriophages their specificity in the production of lysis on the solid medium of cultures of different species of nodule organisms individually and separately was tested. The results are given in Table II. It will be seen that berseem bacteriophage and sweet pea bacteriophage touched cultures of berseem and sweet pea organisms in direct and cross inoculations, gram bacteriophage touched both gram and lucerne organisms while lucerne phage did not touch the gram organisms, the other bacteriophages touched only their own organisms but not others. It seems some of the bacteriophages are specific for their own organisms.

TABLE I

Bacteriophage in legumes

Legume	2 weeks	4 weeks	6 weeks	8 weeks	10 weeks
1. Berseem	− − −	+ + +	+ + +	+ + +	+ + +
2. Sweet pea	− − −	+ + +	+ + +	+ + +	+ + +
3. Lucerne	− − −	− − −	− − +	+ + +	+ + +
4. Karao	− − −	− − −	− − +	+ + +	+ + +
5. Gram	− − −	− − +	+ + +	+ + +	+ + +
6. Dolichos	− − −	− − +	+ + +	+ + +	+ + +
7. Cowpea	− − −	− − −	− − −	− − −	− − −
8. Sannhemp	− − −	− − −	− − −	− − −	− − −
9. *Mung*	− − −	− − −	− − −	− − −	− − −
10. Pea	− − −	− − −	− − −	− − −	− − −
11. Fennugreek	− − −	− − −	− − −	− − −	− − −
12. Meth	− − −	− − −	− − −	− − −	− − −
13. Indigo	− − −	− − −	− − −	− − −	− − −
14. *Arhar*	− − −	− − −	− − −	− − −	− − −

TABLE II

Organism	Bacteriophage					
	Berseem	Sweet pea	Lucerne	Karao	Gram	Dolichos
Berseem	0	0	..	..	..	..
Sweet pea	0	0	..	..	..	..
Lucerne	..	..	0	..	0	..
Karao	..	..	..	0	..	..
Gram	..	..	..	..	0	..
Dolichos	..	..	..	..	..	0

Work done at Delhi. On the transfer of the Institute from Pusa to Delhi in 1936 it was necessary to freshly isolate bacteriophage from the root nodules of berseem as the cultures of berseem bacteriophage were contaminated in transit. The Agricultural Farm of the Institute started growing berseem in Delhi area, for the first time in 1936-37. Previously no such fodder crop was grown in this area. Samples of berseem nodules were collected in 1936-37 in January and in March. The samples were analysed for the presence of bacteriophage. But no bacteriophage could be isolated. This trial was repeated in 1937-38 and 1938-39 without any success. While at Pusa berseem bacteriophage was easily isolated from the nodules of berseem plants growing in the berseem fields. These plots were holding berseem stands for a number of years. The failure to isolate any bacteriolytic principle from the berseem plants growing at the Delhi Farm led to the supposition that bacteriophage is produced in certain soil but not in others. With this end in view it was decided to study the berseem plants growing in Lyallpur and Karnal soils. In March 1941 six samples of berseem nodules were

collected from Lyallpur farm from plots growing berseem for two, six and twelve years; and four samples from Karnal farm from plots growing berseem for one, two, three and five years. These samples were stored in sterile test tubes and brought to Delhi for analysis. The results of analysis of these samples for the presence of bacteriophage are given in Table III.

TABLE III

Presence of bacteriophage in the nodules of berseem plants growing at Lyallpur and Karnal farms

	Place	Phage after 24 hr.	Phage after 48 hr.	Phage after 72 hr.
1. Berseem growing in the plots for 2 years .	Lyallpur .	+ − −	+ − −	+ − −
2. Berseem growing in the plots for 2 years	Lyallpur .	− − −	+ − −	− − −
3. Berseem growing in the plots for 6 years .	Lyallpur .	+ + −	+ + +	+ + +
4. Berseem growing in the plots for 6 years .	Lyallpur .	+ − −	+ + −	+ + +
5. Berseem growing in the plots for 12 years in rotation	Lyallpur .	+ − −	+ + −	+ + −
6. Berseem growing in the plots for 12 years in rotation	Lyallpur .	+ − −	+ + −	+ + −
7. Berseem growing in the plots for 1 year .	Karnal .	− − −	− − −	− − −
8. Berseem growing in the plots for 2 years .	Karnal .	− − −	− + −	− + −
9. Berseem growing in the plots for 3 years .	Karnal .	− − +	+ + −	+ + −
10. Berseem growing in the plots for 5 years .	Karnal .	+ + −	+ + +	+ + +

The results of investigations on bacteriophage both at Lyallpur and Karnal gave a new outlook on this subject. It will be seen from Table III that the plots having berseem stand for 1 to 3 years rarely produce any bacteriophage, while plots having berseem stands for more than 3 years always produce bacteriophage in the nodules of berseem plants. This gave us the solution as to why we did not get any bacteriophage from the berseem plants growing at the Institute Farm for one, two and three years. From both Lyallpur and Karnal results we arrived at a hypothesis that bacteriophage is produced in plots with Berseem plants for three years and more and that no bacteriophage is produced in plots which have got berseem stand less than 3 years old. In support of our hypothesis we have got the work of Demolon and Dunez [1935] in France, and Vandecaveye and Katznelson [1936] in America. A brief summary of their work will not be out of place to mention here.

Demolon and Dunez [1935] succeeded in isolating bacteriophage from the nodules, roots and stems of all alfalfa over one year old on alfalfa sick soils or what they called 'fatigued alfalfa fields' in a number of districts in France, but experienced difficulty or failed in finding it in the roots of alfalfa over 3 years old or in those of old alfalfa plants devoid of nodules. They also isolated bacteriophage from the soil carrying old stands of alfalfa, but not from soils in other crops or carrying young stands of alfalfa. They are of opinion that the presence of this lytic agent in the soil or in plant tissues interferes with normal symbiosis of the nodule bacteria and the host plant. Vandecaveye and Katznelson [1936] isolated a potent lytic principle active against four out of five laboratory stock cultures of Rhizobium moliloti from each of two soils from the Yakina district carrying 3 years old alfalfa stands. They failed to isolate any bacteriophage from the soils carrying alfalfa plants less than 3 years of age. In their case the most common sources of bacteriophage were the soil from fields occupied by alfalfa off and on for many years and 3 and 4 years old stands. Nodulation, on the whole, was poor on plants in fields from whose soils lytic principles were isolated. They could not arrive at any definite conclusion as to bacteriophage being responsible for the reduced yields of alfalfa.

In the light of experience gained at Lyallpur and Karnal and on a line similar to the work of Vandecaveye and Katznelson work was started at Delhi in 1941-42 comprising laboratory, field and pot experiments. In the top block area of Farm berseem was growing since 1937-38 and comprised plots carrying berseem stands for two, three, four and five years. Nodules from these plots were collected during two seasons, 1941-42 and 1942-43 and were examined for the presence of bacteriophage. Two samples were collected—one in January and the other in March. The results of these analyses are given in Tables IV and V.

It will be seen from Tables IV and V that in Delhi soil also bacteriophage was produced in the plots which were bearing berseem stands for three years and more. The soils from the plots having berseem plants for three years and more were

TABLE IV

Production of bacteriophage in Delhi soil (1941-42)

Plot No.	No. of years under berseem	Sample I	Sample II
1. Top Block Plot 2	4 years	+ + +	+ + +
2. Top Block Plot 4	3 years	+ − −	+ − −
3. Top Block Plot 6	2 years	− − −	− − −
4. Middle Block A 1	1 year	− − −	− − −

TABLE V

Production of bacteriophage in Delhi soil (1942-43)

Plot No.	No. of years under berseem	Sample I	Sample II
1. Top Block Plot 2	5 years	+ + +	+ + +
2. Top Block Plot 4	4 years	+ + +	+ + +
3. Top Block Plot 6	3 years	− + +	− + +
4. Middle Block A 1	2 years	Not sown with Berseem	
5. Middle Block A 5	1 year	− − −	− − −

examined for the presence of bacteriophage and were found to contain bacteriophage; while the soils having berseem plants less than 3 years did not contain any bacteriophage. Thus we have confirmed the work of Vandecaveye and Katznelson that bacteriophage does not appear in soils or in nodules of plants growing in the soil for less than three years.

In the light of experience gained by our work at Delhi we will now try to explain why we failed at Pusa to isolate bacteriophage from some of the leguminous plant nodules. At Pusa, bacteriophage was isolated from berseem, sweet pea, karao, dolichos, gram and lucerne. These plants were growing in the same plots at the pot culture area for a number of years. These, by their association with the same soil for a number of years, developed bacteriophage in their nodules, whereas in the case of cowpea, fennugreek, sunn-hemp, *mung*, pea, math and indigo, they were planted one or two times, each in a small plot, simply for the isolation of bacteriophage. The plots varied year after year. This is why we failed to isolate bacteriophage from the nodules of these latter plants as they were not in the same soil for more than one year. In order to test the validity of this statement, pea, fennugreek, lentil, khesari, sweet pea were grown for three years in the same pots each having four separate pots. The nodules of these plants were examined for the presence of bacteriophage. The results are given in Table VI. It will be seen from the table that bacteriophage appeared in pea, sweet pea and began to appear in fennugreek and khesari in the third year of their growth in the same soil. No bacteriophage appeared in the lentil in the third year.

TABLE VI

Produce of bacteriophage in different lagumes

	1941-42		1942-43		1943-44	
	Sample I	Sample II	Sample I	Sample II	Sample I	Sample II
1. Pea	− − −	− − −	− − +	− − −	+ − −	+ + +
2. Fennugreek	− − −	− − −	− − +	− − −	− − −	+ − −
3. Lentil	− − −	− − −	− − −	− − −	− − −	− − −
4. Khesari	− − −	− − −	− − −	− − −	+ − −	+ − −
5. Sweet pea	− − −	− − −	− − −	− − −	+ + −	+ + +

Viability of bacteriophage in soil. Viability of bacteriophage in soil was studied by examining soils containing bacteriophage. In March 1942 eight samples of soil were collected aseptically from Plot A 1 Middle Block growing berseem for the last five years. Five of these soils showed presence of bacteriophage. These soils were kept in the laboratory under the same aseptic condition. They were tested in December 1942 after a period of nine months for the presence of bacteriophage. Almost all of them showed the presence of bacteriophage. It is evident that bacteriophage can survive in the soil for a considerable length of time. The results are given in Table VII.

TABLE VII

Viability of bacteriophage

Soil from Middle Block A 1	March 1943	December 1943
1. Plot B	+++	+++
2. Plot D	+++	+++
3. Plot F	+++	+++
4. Plot G	+++	+++
5. Time of sowing plot	+++	+++

Action of various manures on the production of bacteriophage. In order to study the action of different manures on the production of bacteriophage, samples of nodules from berseem plants were collected from top block plot 1 manurial experiment plots. These plots were under berseem for the last three years. Six plots were selected with different treatments (1) F. Y. M. 80 lb. N, (2) Activated sludge 80 lb. N, (3) Am_2SO_4 80 lb. N, (4) Superphosphate 4 md., (5) Complete minerals, (6) No manure. The nodules were examined for the presence of bacteriophage. The results are tabulated in Table VIII. It will be seen that application of activated sludge, ammonium sulphate and superphosphate favours the production of bacteriophage in the nodules of berseem plants. This experiment has been done for the first time this year and has not been confirmed by subsequent work.

SUMMARY

The root nodules of different leguminous plants were examined for the presence of bacteriophage. While some of the leguminous plants contained bacteriophage in their nodules, others did not show the presence of any. The reason for the presence of bacteriophage has been found to be the association of the plants with same soil for a number of years.

The specificity of bacteriophage has been studied and bacteriophage has been found to be specific for the host plant while some of them cross-inoculate. Viability experiments conducted show that when kept under aseptic condition the bacteriophage remains active for several months. Action of manures on the production of bacteriophage has been studied and it is found that ammonium sulphate, superphosphate and activated sludge favour production of bacteriophage in the root nodules.

TABLE VIII

Presence of bacteriophage

Treatment	23 February 1943	26 March 1943	27 April 1943
1. Plot B F. Y. M. 80 lb. N	− − −	− − −	− − −
2. Plot D Activated sludge 80 lb. N	+ − −	+ − −	+ − −
3. Plot F Am_2SO_4 80 lb. N	+ + −	+ − −	+ + −
4. Plot G Superphosphate 4 md.	+ + −	+ − −	+ + −
5. Plot K Complete minerals on the basis of B	− − −	− − −	− − −
6. Plot L No manure	− − −	− − −	− − −

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EFFECT OF ALGAL GROWTH ON THE ACTIVITY OF *AZOTOBACTER* IN RICE SOILS

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(With Plate VI)

The appearance of an abundant growth of algae in submerged rice-fields is a very common phenomenon. Several workers have investigated the rôle of these algae in the transformation of nitrogen in rice soils. De [1936] observed considerable fixation of nitrogen in some rice soils, in which an abundant growth of algae had taken place, after they had been waterlogged and exposed to sunlight for some time. He concluded that the agents responsible for this fixation are certain blue-green algae, and that the part played by *Azotobacter* in this process is relatively unimportant and possibly nil [De, 1939]. Recently Singh [1942] isolated some nitrogen-fixing blue-green algae from rice soils of Bihar and the United Provinces, and observed that these algae are responsible for nitrogen recouperation in these soils. But Chaudhuri [1940], working with rice soils from Faridpur* (Bengal), concluded that algae play a relatively unimportant part in a direct manner in fixing atmospheric nitrogen in the rice-fields, but that the dead algal bodies provide a suitable medium for the growth of *Azotobacter*, on which the latter thrives bringing about considerable fixation of nitrogen. According to him, therefore, it is *Azotobacter*, and not algae, which fixes nitrogen in rice-fields. It is noteworthy, in this connection that several workers have studied the effect of associated growth of pure cultures of algae and *Azotobacter* on the fixation of nitrogen, but obtained no evidence that the former exerts any beneficial effect on the growth and activity of the latter.

Lipman and Teakle [1925] observed small increase in nitrogen (0·5 mg. in 50 c.c. of medium) when *Chlorella* and *Azotobacter* were grown together. The increase, however, is small enough to lie within the experimental error of the nitrogen determination. Allison and Morris [1930] reported that there was no increase in nitrogen fixation when *Azotobacter vinelandii* was grown in association with each of four species of green algae. De [1939] made cultures of two species of blue-green algae with *Azotobacter chroococcum*, and found that the fixation by the associated growth was same as by algae themselves. Recently Stokes [1940] studied the effect of nine strains of green algae on the growth of *Azotobacter chroococcum* and *Azotobacter vinelandii*. *Azotobacter* failed to make appreciable growth in presence of actively growing cultures of algae, or when supplied with their dead cells or the secretion products as the sole source of nitrogen and carbon. From the results the author concluded that the indirect rôle of the majority of soil algae in the fixation of atmospheric nitrogen either is nonexistent or functions to only very small extent.

The present investigation has been undertaken to study the effect of algal growth on the activity of *Azotobacter* in rice soils. It was thought that the knowledge obtained would be useful firstly in deciding whether algae really favour *Azotobacter* growth in rice-fields, and secondly in ascertaining the rôle played by this latter organism in the fixation of nitrogen in these soils.

Experimental

Materials

The algal materials used in this investigation were obtained from Faridpur soil—the same soil as was used by De and Chaudhuri in their experiments. Small portions of algal growths were collected before harvest when the soil was still waterlogged, without disturbing the soil as far as possible. The samples were rapidly dried first in air and then in an oven at 80°C., finely powdered and then preserved for use in the experiment. The nitrogen content of the dry powder was 2·12 per cent. Microscopic examination of the moist growth showed that it was rich in blue-green algae.

Availability of the dead algal bodies as energy materials for Azotobacter

To investigate the availability of the dead algae as a source of energy for *Azotobacter*, 100 c.c. portions of a nitrogen-free solution,§ containing one gram of powdered algal material, were incubated at 30°C. after inoculation with a suspension of soil. A second set of cultures, using mannite (an excellent source of energy for *Azotobacter*) in place of powdered algae, were simultaneously

*De [1939] made an extensive study of this particular soil, from which he isolated some nitrogen-fixing blue-green algae and concluded that these algae directly fix nitrogen in this soil

§K_2HPO_4 — 0·5 gm., $MgSO_4$, $7H_2O$ — 0·2 gm. Na_2MoO_4—0·025 gm., $CaCO_3$—5 gm., $FeCl_3$—0·05 gm., and water 1,000 c.c.

started in order to compare the relative availabilities of these two materials. At the end of 7 and 15 days, duplicate cultures from each treatment were analysed for total nitrogen by Kjeldahl method, there being no nitrate in any of the cultures. The results are shown in Table I.

TABLE I

Nitrogen fixed in culture solutions

(From 26 February to 12 March 1943)

N in mg. in 100 c.c. of the culture solution

Energy material	At start	After 7 days	Fixed in 7 days	After 15 days	Fixed in 15 days
Dead algae	21·5	22·0	0·5	21·5	0·0
Mannite	0·3	9·7	9·4	13·7	13·4

The results in Table I show that the dead algae are not readily available to *Azotobacter* as a source of energy.

Changes in Azotobacter *and total bacterial numbers*

In order to observe the effect of algal growth on the changes in *Azotobacter* and bacterial numbers, 20 gm. portions of soils were distributed in a number of 250 c.c. Erlenmeyer flasks, half of which were previously wrapped with glazed black paper to exclude sunlight. The soils were brought to waterlogged conditions by the addition of either 200 c.c. of distilled water or an equal volume of a nitrogen-free solution, the latter treatment having been found to stimulate algal growth (K_2HPO_4—0·5 gm., $MgSO_4$, $7H_2O$—0·2 gm., $CaSO_4$—0.1 gm., $Ca_3(PO_4)_2$—1.0 gm., $FePO_4$—0·1 gm., water 1,000 c.c.). After the flasks had been plugged with cotton wool and their necks covered with loose rubber caps to prevent rain water, they were all placed in a bath of running water whereupon the whole arrangement was exposed to sunlight. Algae appeared in all flasks in the light, but in none in the dark, i.e. in flasks covered with black paper. At intervals of 15 days, one flask from each treatment was removed for the determination of *Azotobacter* and total bacterial numbers. Total nitrogen was determined after 30 and 60 days.

Azotobacter was determined by a method developed by Jensen [1940]. In this method 0·2 c.c. portions of a soil dilution of 1 : 10 are placed on three sterilized petri dishes containing hardened dextrin-agar medium (medium described earlier, made with 1 per cent dextrin and 2 per cent agar), and evenly spread over by means of a L-shaped glass rod. The excess of water is allowed to evaporate. The plates are incubated at 30°C. for five days after which the colonies are counted. An advantage of this method is that the colonies formed are discreet and very easily distinguishable (Plate VI, fig. 1).

In the present experiment the ratio of soil and water in each flask at start was 1 : 10 (20 gm. of soil in 200 c.c. of water or solution), i.e. the same ratio as is necessary for counting. In the beginning of the experiment, each flask was marked with a glass pencil to indicate the level of the liquid. Before counting the level was brought to this mark by the addition of sterilized water where necessary. Such addition, however, was not generally required as the evaporation of the liquid from the cultures was very little. The flask was then closed with a sterilized rubber cork, vigorously shaken for three minutes and 0·2 c.c. portions of the suspension plated as above.

For bacterial counts, the above suspension (1:10) was further diluted, one c.c. portions of a dilution of 1 : 100,000 being plated with Thornton's [1922] agar. Four Parallel plates were run, which were incubated at 30° C. for seven days, after which the colonies found were counted.

The results of nitrogen determination, and of *Azotobacter* and bacterial counts are shown in Tables II, III and IV respectively.

A reference to Table III shows that the numbers of *Azotobacter* were consistently lower in the light than in the dark, i.e. in presence of algae *Azotobacter* was less abundant. But the results in Table II show that fixation of nitrogen took place only in the flasks in which algal growth had taken place. Thus there is no correlation between nitrogen fixation and *Azotobacter* growth. If the latter organism was really involved in the process, then there would have been fixation (and perhaps in greater amount) in the dark as well where it was present in higher numbers. It will also be remembered that nitrogen fixation is a function of the growth of the nitrogen-fixing organisms, consequently if a particular organism is fixing

TABTE II

Fixation of nitrogen in rice soils

(From 19 May to 17 July 1942)

N in mg. per culture flask

Locality	Days	Soil+Water				Soil+Solution			
		Light		Dark		Light		Dark	
		Total	Fixed	Total	Fixed	Total	Fixed	Total	Fixe
Coimbatore, Madras	0	15·2	..	15·2	..	15·2	..	15·2	..
	30	17·2	2·0	15·0	—0·2	17·2	2·0	14·9	—0·3
	60	18·0	2·8	15·0	—0·2	19·7	4·5	15·0	—0·2
Sabour, Bihar	0	22·0	..	22·0	..	22·0	..	22·0	..
	30	25·0	3·0	21·9	—0·1	26·1	4·1	22·0	0·0
	60	26·1	4·1	21·8	—0·2	28·9	6·9	21·9	—0·1

TABTE III

Effect of algal growth on the changes in Azotobacter *numbers*

(From 19 May to 17 July 1942)

Azotobacter *per 0·1 gm. of dry soil averages are in brackets*

Locality	Days	Soil+Water		Soil+Solution	
		Light	Dark	Light	Dark
Coimbatore, Madras—pH=8·40	0	340	340	340	340
		310(333)	310(333)	310(333)	310(333)
		350	350	350	350
	15	135	200	180	240
		120(127)	175(187)	175(178)	255(240)
		125	185	..	225
	30	150	205	200	315
		130(142)	230(212)	205(215)	340(342)
		154	200	245	370
	45	160	300	240	315
		170(160)	325(327)	230(235)	310(330)
		150	355	235	365
	60	105	240	250	360
		105(110)	280(262)	245(253)	320(335)
		120	265	265	325
Sabour, Bihar—pH=8·30	0	500	500	500	500
		520(500)	520(500)	520(500)	520(500)
		480	480	480	480
	15	235	250	475	500
		250(242)	265(252)	450(452)	500(513)
		240	240	430	540
	30	300	450	470	600
		335(315)	480(478)	485(492)	630(600)
		310	505	520	570
	45	300	590	455	645
		360(320)	530(552)	425(440)	620(650)
		300	535	440	685
	60	120	600	385	640
		115(125)	585(600)	380(390)	630(625)
		140	615	405	605

nitrogen in a certain environment, its number should show enormous increase at some stage at least during the process. But as seen in Table II, in none of the soils and at no stage of the experiment, did *Azotobacter* show any tendency to multiply, showing thereby that the conditions occurring in the cultures were never suitable for its growth. All these facts go to prove that *Azotobacter* does not play any part in the fixation of nitrogen in rice soils under waterlogged condiions.

TABLE IV

Effect of algal growth on the changes in bacterial numbers

(From 19 May to 17 July 1942)

Bacteria as millions per gm. of dry soil; average of 4 plates

Locality	Days	Soil+Water		Soil+Solution	
		Light	Dark	Light	Dark
Coimbatore, Madras . .	0	3·60	3·60	3·60	3·60
	15	12·10	14·02	12·52	14·86
	30	16·40	21·50	17·20	21·00
	45	11·60	16·60	12·70	17·50
	60	5·65	13·75	12·00	17·33
Sabour, Bihar	0	5·10	5·10	5·10	5·10
	15	11 55	15·77	13·60	16·30
	30	13·13	18·90	14·25	14·55
	45	8·73	16·05	7·80	12·45
	60	8·60	13·00	7·90	11·25

Like *Azotobacter*, bacterial numbers were also less in presence of algae.* It was also suspected that some products, toxic to *Azotobacter* and other bacteria, might have been formed in the soil as a result of algal growth. The following experiment was undertaken to test this possibility.

Two equal amounts of a rice soil were brought to waterlogged conditions by the addition of same volume of distilled water and then exposed to sunlight, after having covered one with black paper. As observed in other experiment, algae appeared only in the soil kept in the light. After two months, the supernatant water from each was carefully siphoned off and filtered. Chemical analysis showed that the filtrates contained very little N (l p.p.m.) and no phosphate. Using these two filtrates in place of distilled water, two dextrin-agar media were prepared according to the formula given previously. Equal volumes of the melted media were hardened in petri dishes of same size, and by means of a glass pencil a straight line, 1 cm. in length, was drawn on the bottom side of the lower half of each petri dish. The plates were inoculated by streaking a loopful of a suspension of *Azotobacter* in water over the medium just above and from end to end of the line drawn. In this way the conditions of inoculation were standardized —the number of cells in each inoculum and the amounts of nutrients available to them being kept constant as far as possible.

Plate VI, fig. 2 shows the growth of *Azotobacter* in the two media after 5 days' incubation at 30°C. The growth is apparently considerably less in the medium made with the water from soil containg algal growth. In fact, when freshly prepared media were used, the difference was more marked than as shown in Plate VI, fig. 2. It will be seen that the two plate cultures were made under exactly similar conditions, except that the samples of water used in the preparation of the media were obtained from different sources. The difference in growth must, therefore, be due to the difference in qualities of the two water samples. Evidently the sample obtained from soil with algal growth had contained something which inhibited the

growth of *Azotobacter*. This explains why this organism was less abundant in presence of algae.

Decomposition of dead algal bodies

After harvest rice soils are allowed to dry up when the algae which had appeared during the previous waterlogged period die, forming a dry scum over the soil surface. The material ultimately decomposes in the soil, the conditions of which remain very suitable for bacterial activity, particularly during the few months in winter. The average temperature lies between 25-30°C., and there remains in the soil sufficient moisture to favour the growth of the micro-organisms

In order to find whether the decomposition of dead algae in soil under dry conditions leads to fixation of nitrogen, 100 gm. portions of soils were distributed in two glass dishes, one of which remained untreated and the other received an addition of 2·5 gm. of powdered algal bodies. The moisture contents of the soils were adjusted to 15 per cent on dry basis and were maintained at this value throughout the experiment by periodic additions of water. The dishes were placed in an incubator at 30°C., and the soils were daily stirred to facilitate aeration. At intervals, soil samples were withdrawn for determination of total nitrogen and for *Azotobacter* and bacterial counts. Total nitrogen was determined by the modified Kjeldahl wet method, there being no nitrate accumulation in the soils. *Azotobacter* and bacteria were counted by the methods already described.

Results of nitrogen determination are given in Table V and *Azotobacter* and bacterial counts in Tables VI and VII respectively.

TABLE V

Decomposition of dead algal bodies on nitrogen fixation

(From 26 February to 26 April 1943)

N in mg. per 100 gm. dry soil

Locality	Treatments	At start	After 15 days	After 30 days	After 45 days	After 60 days	Fixed in 60 days
Faridpur, Bengal	No treatment .	47·0	48·0	46·5	47·0	47·0	0·0
	Algae* . . .	100·0	101·0	100·0	97·5	96·0	—4·0
Coimbatore, Madras	No treatment . .	82·0	..	81·0	82·0	81·5	—0·5
	Algae	135·0	..	135·0	132·0	130·5	—4·5
Sabour, Bihar .	No treatment . .	116·5	..	116·8	116·0	117·0	+0·5
	Algae	169·5	..	170·0	167·0	165·0	—4·5

*N added with 2·5 gm. of powdered algae=53·0 mg.

Results in Table V show that, instead of there being any fixation of nitrogen, considerable loss of this element took place from every soil treated with powdered algae. It is not known how this loss was brought about, but this is a common observation that when soil is treated with materials rich in nitrogen, some loss of this element generally takes place. At any rate, there is no evidence that nitrogen-fixation takes place in the rice soils as a result of the decomposition of dead algae.

This conclusion is also supported by *Azotobacter* counts which showed no sign of multiplication (Table VI). But the total bacteria multiplied enormously both in the control as well as in the treated soil—considerably more in the latter (Table VII). This shows that the addition of algae had made the soil more favourable for bacterial growth; this observation further suggests that the 'inhibitory substances' formed in the waterlogged soil probably did not survive under dry conditions.

The foregoing evidences are definitely against the view that *Azotobacter* fixes nitrogen in rice soils, utilizing the dead algal bodies as energy source. Chaudhuri [1940] came to such conclusion with respect to rice soils of Bengal, but he has given no data and practically no evidence in support of his statements.

In this investigation only the rôle played by *Azotobacter chroococcum* has been considered. This is the most commonly occurring species which has been found to be widely distributed in Indian

TABLE VI

Decomposition of dead algal bodies on Azotobacter *numbers*

(From 26 February to 6 April 1943)

Azotobacter *per* 0·1 *gm. of dry soil averages are in brackets*

Locality	Days	Treatments	
		No treatment	Algae
Coimbatore, Madras $pH=8\cdot40$	0	227 205(223) 238	227 205 (223) 238
	10	205 228(209) 194	181 170(181) 192
	20	279 302(283) 267	205 194(198) 194
	30	219 184(204) 209	148 160(152) 148
	40	270 290 (280) 280	212 198(199) 187
Sabour, Bihar $pH=8\cdot30$	0	393 424(403) 393	393 424(403) 393
	10	765 765(743) 700	620 630(616) 597
	20	640 700(660) 640	410 390(400) 400
	30	1200 1150(1150) 1100	607 607(598) 580
	40	1370 1310(1320) 1280	680 690(670) 640
Faridpur, Bengal $pH=8\cdot35$	0	20 20(20) 20	20 20(20) 20
	10	10 10(10) 10	10 0(3) 0
	20	137 126(126) 114	0 0(0) 0
	30	239 219(229) 228	10 10(10) 10
	40	260 236(252) 260	10 10(7) 0

rice soils. The recently discovered *Azotobacter indicum* [Starkey and De, 1939] has been found only in a few soils, and as regards other species of this genus, their occurrence in Indian rice soils has not been demonstrated. Besides *Azotobacter*, *Clostridium pasteurianum* and other anaerobic nitrogen-fixing bacteria might also play an important rôle in the process particularly during the waterlogging periods when the conditions of the soil remain partly anaerobic. This possibility is at present under investigation, the results of which will be published in due course.

TABLE VII

Decomposition of dead algal bodies on bacterial numbers

(From 26 February to 6 April 1943)

Bacteria as millions per gm. of dry soil; average of 4 plates

Locality	Days	Treatments	
		No treatment	Algae
Coimbatore, Madras	0 10 20 30 40	3·5 7·0 155·2 552·5 602·0	3·5 21·0 225·0 765·0 1040·0
Sabour, Bihar	0 10 20 30 40	6·0 62·1 179·0 370·0 628·3	6·0 109·0 225·7 506·2 930·0
Faridpur, Bengal	0 10 20 30 40	1·7 12·3 73·0 343·7 421·6	1·7 38·7 107·8 592·0 702·0

SUMMARY

There was no fixation of nitrogen when a culture solution, made with the necessary nitrogen-free nutrients and dead algal bodies from a rice field as the source of energy, was inoculated with a suspension of soil, showing that these algae do not serve as energy materials for nitrogen fixation.

Periodic estimations of *Azotobacter*, and total bacteria in waterlogged rice soils, kept in the light (algae present) and also in the dark (algae absent), showed that the numbers of these organisms were consistently less in the former, in spite of the fact that in these cultures nitrogen fixation had taken place. The results further showed that *Azotobacter* failed to multiply in either treatment. Evidence was obtained that some materials toxic to *Azotobacter* are formed in rice soils under waterlogged conditions as a result of algal growth.

Determinations of total nitrogen at intervals in soils, treated with and without dead algae and kept under optimum conditions of temperature and moisture, showed considerable loss from the former. Here again *Azotobacter* was relatively less in the soil treated with algae and there was

FIG. 1. Plate Counts of *Azotobacter* on dextrin-agar. Incubated 5 days at 30°C.

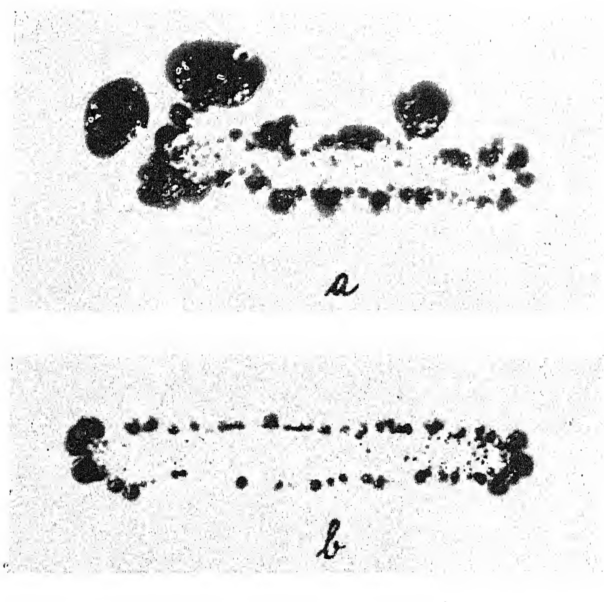

FIG. 2. *Azotobacter* growth on dextrin-agar plate. Incubated 5 days at 30°C.

a—Medium made with water from a soil without algal growth

b—Medium made with water from the same soil with algal growth

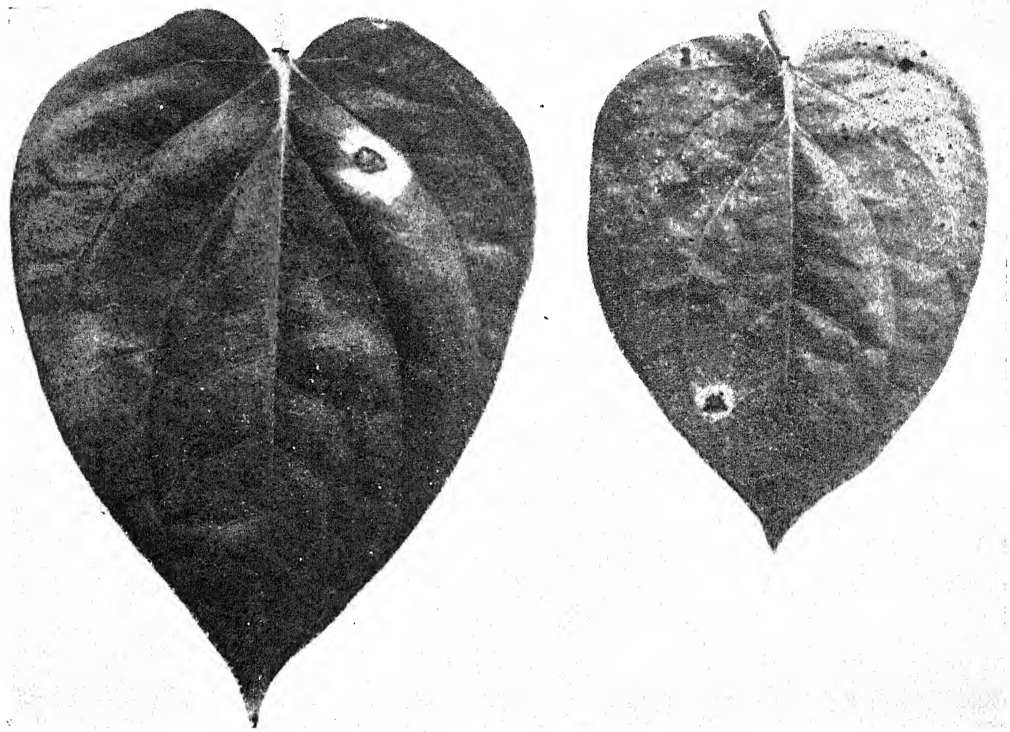

FIG. 1. Bacterial leaf-spot on betel leaf, early stage

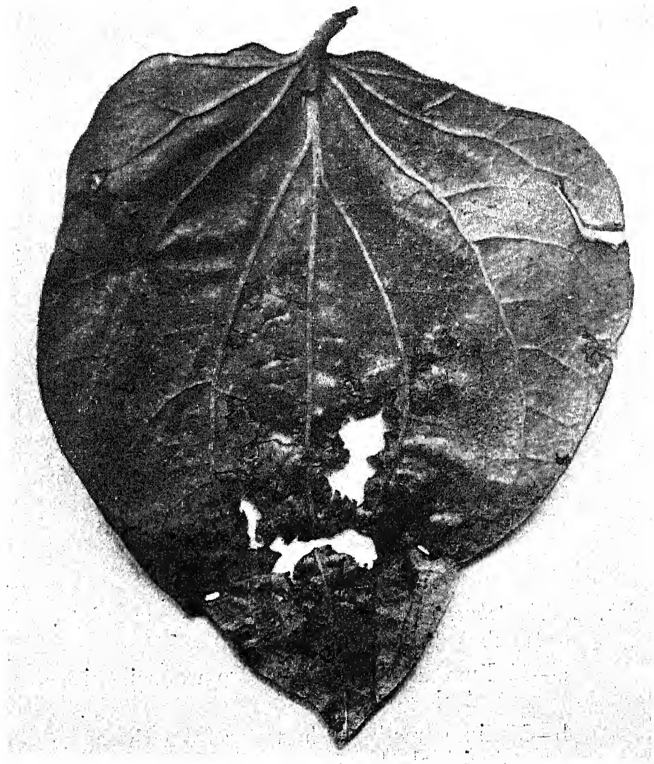

FIG. 2. Bacterial leaf-spot on betel leaf, advanced stage

no sign of its multiplication in either treatment. Total bacteria, on the other hand, showed increase in both treatments—much more in presence of algae. It is presumed that the failure of *Azotobacter* to multiply in these soils is partly due to competition with total bacteria for the supply of available nutrients.

From the evidences obtained it is concluded that the algal growths in the rice-fields do not provide a suitable medium for the growth of *Azotobacter*, and further that this latter organism does not bring about any nitrogen-fixation when using the dead algal bodies as source of energy.

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BACTERIAL LEAF-SPOT OF *PIPER BETLE*

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(With Plate VII)

Bacterial leaf-spot disease of *pan* (*Piper betle*) has been known to exist in the Central Provinces and Berar for more than a century. This disease, called *kinrog* by local *pan* growers, attracted little attention till 1933 when a survey was undertaken to determine its intensity at different *pan*-growing centres. The disease has been reported from Ramtek, Pauni, Sohagpur, Mandla, Timarni, Anjangaon, Saugor, Damoh, Bhandara, Drug and several other places in the province. It has been observed that all the varieties of *pan* that are cultivated in this province, viz. *kapuri*, *bangla*, *kakher* and *gangeri* are susceptible to it to varying degrees of intensity and the annual loss caused by it is considerable.

Hutchinson [1924] described a bacterial disease on stem of betel vine in Bengal and in 1925 he reported that the bacterium isolated from the diseased material failed to give conclusive results, though, later in the year, one or two individuals showed symptoms of the disease. Raghunathan [1926] was the first to report the bacterial leaf-spot of betel, which was recorded in Ceylon in 1896. He mentions that from 1921 onwards the disease did considerable damage to cultivations in several localities in the low country and was most prevalent during the monsoon. The cause of the disease was attributed to a bacterium which he named as *Bacterium betle*. The symptoms of the disease have been mentioned. As control measures, destruction of all diseased material six months of rotation with vegetables and general sanitation have been recommended. Later Raghunathan [1928] published a fuller account of his investigations. He gave a technical description of the organism, whose group number according to the chart of the Society of American Bacteriologists, was 2,11,00,00,514. Nirula [1931] described a bacterial disease of betel leaves during storage. Symptoms, methods of infection and the characters of the pathogen show that the disease as described by him is quite different from the one which is being described here. Park [1934] has redescribed the symptoms, the methods of transmission and of control of the leaf spot caused in Ceylon by *Bacterium betle*.

The earliest symptom of the disease is the presence of minute transluscent specks in-between the veins on the underside of the leaves. With in two to three days these transluscent specks

are visible on the upper surface as circular or angular brown to dark-brown spots, surrounded by yellow coloured zones (Plate VII, fig. 1). On the underside of the leaves the areas corresponding to the yellow zones are somewhat water-soaked in appearance. When atmospheric conditions are dry the spots are localized and minute, measuring 1 to 5 mm. in diameter ; but with the advent of humid and wet weather, they get considerably enlarged and measure up to 1 cm. across. In old and large spots the central portion often cracks or falls off (Plate VII, fig. 2). The number of spots on a leaf varies according to the prevailing weather conditions. When the atmosphere is humid the spots often coalesce, causing larger patches of dead areas on the leaf blade. Such leaves gradually loose their lustre, become flaccid turn pale and finally fall off. A gummy substance full of bacteria oozes out during wet weather and gets deposited on the underside of an infected leaf. The disease has never been observed to occur on stems, petioles, or roots.

In a *pan* garden the disease is mostly evident on leaves which are near or touching the soil surface. During dry weather the infection is confined to a height of 1 ft. of the vines but during wet seasons it extends to a height of 3 ft. due to the splashes of rain water. Mites have been observed to carry the infection from leaf to leaf. Whenever these insects appear in virulent form the disease spreads even up to a height of 5 ft. of the vines. Rain water and insects are the chief carriers. The disease has been observed to be more prevalent in gardens with heavy soils than in gardens with light soils. *Pan* vines cultivated in low-lying and waterlogged areas are the greatest sufferers.

At Mandla the incidence of the disease on *bangla* variety of *pan* was recorded monthly from three well-drained high-lying and three low-lying waterlogged gardens for a period of 12 months. The data show that the incidence of the disease was more than double, specially from July to December, in low-lying waterlogged gardens than in high-lying well-drained ones. The average percentage of infection for 12 months was 12·8 in the former and 5·9 in the latter. In both the cases the disease was more pronounced during wet weather and scarce during dry months with scanty or little rainfall.

Experiments very much similar to that of Mandla were carried out at Ramtek for three years, 1941-43. Here the incidence of the disease was recorded on two varieties of betel leaves, viz. *bangla* and *kapuri*, the latter proving more susceptible to the disease than the former. Temperature and humidity played important röles on the incidence of the disease. High atmospheric temperature with little or scanty rainfall definitely retarded the incidence of the disease while, during wet months of July, August and September, the infection was very high on both the varieties.

Pure cultures of the pathogenic bacteria were isolated. On glucose agar medium honey-yellow coloured colonies appeared within three days of inoculations. The individual organisms are cylindrical in shape with the ends slightly rounded and measure $1 \cdot 5\text{-}2 \cdot 5 \times 0 \cdot 5\mu$. They are either solitary or in chains of three to four cells, light honey-yellow in colour, non-motile and without spores or capsules. Pathogenic and cultural characters of the organism indicate that it is the same bacterium (*Bacterium betle*) as described by Raghunathan [1926], causing leaf-spot in Ceylon.

Healthy roots, stems, petioles and leaves of betel vines were artificially inoculated with pure cultures of the organism. The disease could be readily transferred to leaves when kept under moist condition. According to the age of the leaves the symptoms appeared within one to four days. Old and mature leaves took up the inoculation much earlier than young and immature ones. Infection was more pronounced on the lower side of the leaves than on the upper side which indicated that the organism made its entry to the host tissue through stomata which are abundant on the lower sides. Unless and until the upper sides of the leaves were injured they did not get infected. The infection on the lower surface appeared within 3 days ; spots were numerous and close together. Invariably in every case inoculations with cultures older than two weeks proved unsuccessful. It was also observed that if the inoculum was placed at the cut end of a stem, the infection advanced at the most to 1 cm. where the tissues turned dark brown and the cells collapsed. In no case was the infection observed to advance to any appreciable length in the cuttings. Healthy roots, stems and petioles when wounded and inoculated gave negative results.

Several experiments were conducted to work out suitable measures of control for the disease. At Timarni spraying trials with Bordeaux mixture (2:2:50), Bouisol (3·5 lb. in 100 gallons of water) and Sulsol (5 lb. in 100 gallons of water) were conducted to find their effects on the incidence of the disease. One gallon of each of the fungicide was sprayed on 75 ft. length of the *pan* rows. Four varieties, viz. *bangla, kapuri, kakher* and *gangeri*, were under trial with the above three fungicides. Only one spraying could be given during August but the results when observed after two months showed that there was 10 per cent disease in unsprayed vines, eight per cent in Sulsol, four per cent in Bouisol and only one per cent in Bordeaux mixture sprayed vines. *Kapuri* was the most

TABLE I

Effect of fungicides on the incidence of leaf-spot disease on large leaves (Bade pan)

Plot No.	Treatment of soil	Treatment of vines	March Air temp.—80·5 Rainfall—0·52			April Air temp.—87·0 Rainfall—0·59			May Air temp.—94·8 Rainfall—0·64			June Air temp.—84·6 Rainfall—13·12			July Air temp.—81·0 Rainfall—14·45			August Air temp.—79·6 Rainfall—13·52			September Air temp.—80·1 Rainfall—7·56			October Air temp.—78·6 Rainfall—7·03			Grand total for the year*		
			Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection
1	No treatment . . .	No treatment . . .	9,490	989	10·4	11,436	497	3·4	15,567	318	2·0	14,322	2,986	20·8	36,185	12,635	34·9	38,387	14,171	36·9	30,652	5.814	18·0	16,848	1,989	11·8	1,72,887	39,399	22·76
2	Bordeaux mixture (2:2: 50), 1 gallon for 6 ft.	No treatment . . .	12,593	898	7·1	11,017	128	1·1	16,223	176	1·0	15.394	1,543	10·0	51,001	12,750	24·9	60,911	12,789	20·9	59,713	8,758	14·6	55.413	2,571	4·6	2,82,265	39,612	14·0
3	Ditto.	Bordeaux mixture (2:2: 50), 1 gallon for 75 ft.	11,989	277	2·3	10,240	32	0·3	15,580	37	0·2	16,452	212	1·2	47,927	2,422	5·0	61,325	1,226	1·8	59,918	1,989	3·3	57,769	31	0·5	2,81,200	6,507	2·3
4	Ditto.	Bouisol (5 lb. in 100 gallons), 1 gallon for 75 ft.	9,633	165	1·7	12,133	27	0·2	14,972	42	0·2	15,913	249	1·5	48.932	3,398	6·0	59,221	1,812	3·0	61,271	2,448	3·9	54,363	401	0·7	2,76,438	8,542	3·0
5	Ditto.	Sulsol (5 lb. in 100 gallons), 1 gallon for 75 ft.	11,807	948	8·0	10,712	113	1·0	15,719	33	0·2	14,957	1,072	7·1	48,761	11,902	24·4	61,017	10,980	17·9	59,676	8,040	13·5	56,591	2,286	4·0	2,79,240	35,374	12·6

*For the first four months of the plantation no picking is carried out

TABLE II

Effect of fungicides on the incidence of leaf-spot disease on small leaves (Khilli)

Plot No.	Treatment of soil	Treatment of vines	March Air temp.—80·5 Rainfall—0·52			April Air temp.—87·0 Rainfall—0·59			May Air temp.—94·8 Rainfall—0·64			June Air temp.—84·6 Rainfall—13·12			July Air temp.—81·0 Rainfall—14·45			August Air temp.—79·6 Rainfall—13·52			September Air temp.—80·1 Rainfall—7·56			October Air temp.—78·6 Rainfall—7·03			Grand total for the year*		
			Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection	Total number of picked leaves	Number of infected leaves	Per cent of infection
1	No treatment . . .	No treatment . . .	5,978	708	11·8	5,337	159	2·9	7,908	117	2·7	6,759	1,072	15·8	20,343	5,987	29·4	19,184	6,494	33·6	17,106	2,007	11·7	9,231	744	8·0	91,846	17,288	18·8
2	Bordeaux mixture (2:2:50), 1 gallon for 6 ft.	No treatment . . .	4,383	301	6·8	5,095	25	0·4	8,002	160	1·9	7,624	988	11·6	25,912	4,032	15·5	33,712	5,840	17·3	35,119	5,021	14·2	25,713	780	3·0	1,45,560	17,147	11·7
3	Ditto.	Bordeaux mixture (2:2:50), 1 gallon for 75 ft.	5,079	76	1·4	5,170	12	0·2	7,235	36	0·4	6,902	132	1·9	23,221	598	2·5	33,315	432	1·2	31,712	1,200	3·7	28,919	89	0·3	1,41,553	2,575	1·7
4	Ditto.	Bouisol (5 lb. in 100 gallons), 1 gallon for 75 ft.	4,547	79	1·7	6,706	17	0·2	8,101	40	0·4	7,121	179	2·5	26,715	487	1·8	32,122	1,105	3·4	35,923	2,163	6·0	29,911	307	1·0	1,51,146	4,377	2·8
5	Ditto.	Sulsol (5 lb. in 100 gallons), 1 gallon for 75 ft.	6,042	480	7·9	5,603	67	1·1	7,743	39	0·5	7,619	836	10·9	26,219	5,132	19·13	34,017	6,821	20·0	32,211	3,342	10·3	27,733	1,280	4·6	1,47,187	17,997	12·2

* For the first four months of the plantation no picking is carried out

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susceptible variety. Though Bordeaux mixture proved best of all the tried fungicides yet the *pan* growers preferred Bouisol as it does not leave any trace of the chemical on the leaves whereas in the former they become unsightly and can only be marketed after thorough washing and cleaning with water which involved extra labour and time.

The above experiment was later repeated at Ramtek with only one variety of *pan*, viz. *kapuri*. An area of $\frac{1}{3}$ acre was taken for this trial which had 50 rows of betel-vines. This area was divided into five equal plots, each with 10 rows, and each row being 160 ft. in length. With the exception of plot No. 1, the rest were irrigated with 2:2:50 strength Bordeaux mixture before planting the cuttings. Vines in plots No. 1 and 2 were not given any spraying while 3, 4 and 5 were sprayed with Bordeaux mixture (2:2:50), Bouisol (2·5:50) and Sulsol (2·5:50) respectively at the rate of one gallon for 75 linear lengths of the vines. Irrigation of the soil with Bordeaux mixture (2:2:50) was carried out in November, a week prior to planting, while the spraying was done after three months of it. Subsequently both the treatments were carried out once every two months. The leaves were picked every month and graded into *bade pan* (large) and *khilli* (small) leaves. The results are given in Tables I and II.

In these experiments also the best results were obtained where the soil and the vines were treated with Bordeaux mixture (2:2:50), closely followed by Bouisol (2·5:50). Spraying the vines with Sulsol did not give satisfactory results. Where the soil was treated with Bordeaux mixture and no spraying was given (Plot 2), the incidence of the disease was slightly less than the untreated plot (No. 1) as the infection from soil was minimized. However, this soil treatment alone of plot No. 2 was not at all effective in checking the progress of the disease. It will be further noticed that here again the disease was at its highest during the months of July and August, a period of high humidity and low temperature.

Repeated trials have shown that this disease can be successfully controlled if the following measures are adopted by *pan* growers :

1. The vines when taken off the stake and lowered should be so retied that the lower most leaves are at least one foot above the soil surface.
2. The diseased leaves should be systematically and regularly picked and destroyed by burning.
3. The irrigation channels should be so constructed that no waterlogged areas are created in the garden.
4. In case mites appear in a garden, the infected and neighbouring vines should be sprayed with a solution of fish-oil rosin soap (4 oz.) and nicotine sulphate (1 oz.) or tobacco decoction, in 6 gallons of water. Dusting the vines with finely powdered sulphur (200 mesh) will also remove the mite trouble.
5. One week before planting the cuttings the soil should be irrigated with 4:4:50 strength* Bordeaux mixture and subsequently it should be treated every two months at the rate of 1 gallon for 12 linear ft.
6. The vines should be sprayed with 2:2:50 strength Bordeaux mixture every two months, 1 gallon for 75 ft. length of the vines.

This treatment will also effectively control anthracnose (*Colletotrichum* sp. and *Gloeosporium* sp.) and leaf-rot (*Phytophthora parasitica* Dast. var. *piperina* Dast.) diseases.

The cost of six sprayings per annum per acre will amount to Rs. 13, Rs. 82 and Rs. 82 for Bordeaux mixture, Bouisol and Sulsol, respectively at pre-war rates. The savings over untreated gardens per acre per annum was Rs. 506 for Bordeaux mixture, Rs. 411 for Bouisol and Rs. 162 for Sulsol. These results definitely show that the *pan* growers will be amply rewarded if they take up the recommended treatments.

By spraying the leaves with Bordeaux mixture unsightly stains are left over to which the *pan* growers strongly object. This defect can easily be removed if the sprayed leaves are first dipped in a 2 per cent solution of ammonium chloride for an hour and then washed with water. The extra cost involved in this way will hardly come to Rs. 100 per annum per acre, which will be well within the profit scope of the growers.

It was apprehended that the Bordeaux mixture sprayed leaves, when consumed, might prove harmful. The Agricultural Chemist to Government, Central Provinces and Berar, was therefore requested to conduct the necessary analysis and samples were sent over to him. On the results of the analysis he remarks, 'the maximum amount of copper present in unwashed selected sprayed leaves was 2·45 grains per lb. whereas when the same were washed, the quantity present was 1·11 grains per lb. and the average sample of unwashed leaves from the sprayed vines contained 0·82 grain per lb. Taking an average that 200 leaves weighed one lb. and assuming that the maximum consumption per day per person is 20 betel leaves then the maximum amount of copper taken per day per person, if the leaves are unwashed and if all of them show the spots of dried Bordeaux mixture, would come to 0·24 grain whereas if the leaves are washed—as is the usual practice—the quantity of copper taken per person per day will come to only 0·1 grain, both of which

*Instead of 2:2:50 strength 4:4:50 Bordeaux mixture is recommended as it has been found that this strength will control the bacterial leaf-spot and as well as foot-rot disease

are lower than the maximum that can be taken without causing any injury '. On this report and as well as by every day observation Bordeaux mixture can be safely recommended for spraying the vines as the leaves are always consumed after washing.

Summary

The annual loss to *pan* growers due to bacterial leaf-spot disease in the Central Provinces and Berar is considerable.

Symptoms of the disease are described. The disease is more prevalent during wet weather,in heavy soils and in low-lying waterlogged gardens.

Kapuri variety of *pan* is more susceptible to the disease than *bangla, kakher* or *gangeri* varieties.

The pathogenic organism is similar to *Bacterium Betle* Raghunathan in its cultural and pathogenic behaviour.

Neither by artificial inoculations nor under natural conditions has the bacterium been observed to cause infection to roots, stems or petioles.

The bacterium enters the leaves either through stomata or injured surface.

Irrigating the gardens with 4:4:50 Bordeaux mixture one week prior to planting and spraying the vines with 2:2:50 strength Bordeaux mixture every two months successfully controlled the disease and the cost of treatment will amply reward the growers financially.

Acknowledgement

We wish to express our sincere thanks to Rao Bahadur Dr D. V. Bal, Agricultural Chemist to Government, Central Provinces and Berar, for the analysis of Bordeaux mixture stained leaves.

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STUDIES ON THE VIRUS DISEASES OF POTATOES IN INDIA

I. OCCURRENCE OF SOLANUM VIRUS I

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(With Plates VIII and IX)

During analytical work of viruses of potatoes growing in the field and in the insect proof house at the Imperial Agricultural Research Institute, New Delhi, exhibiting various types of symptoms, e.g. different types of mosaic and necroses, a number of cultures of *Solanum virus* I. Orton [Smith, 1937] were recovered from plants of several potato varieties. A culture of the same virus was also obtained from a plant of *Majestic* variety, the leaves of which showed negligible mottle accompanied with severe veinal necroses. The necroses seemed to have appeared on the undersurface in the first instance and later appeared on the upper surface of the leaves. The plant was stunted and its growth in general was poor. The majority of plants of this variety in this particular field showed mild veinal necroses leading to acropetal necrosis. The plant under reference differed from the others in the fact that it showed intense veinal necroses without its subsequent development into acropetal necrosis. The seed tubers of *Majestic* variety had been obtained from Divisional Superintendent of Agriculture, Bhowali, United Provinces.

Some cultures appeared to be more virulent than others, as determined by the intensity of symptoms produced on the differential hosts. The culture from the plant of *Majestic* variety appeared to be of moderate virulence and experiments were conducted to study its properties. These are reported in this paper.

Material and method

Preliminary analyses were carried out by transferring the extracts of infected potato plants to sets of differentials such as *Datura stramonium L.*, *Nicotiana tabacum* L. var. *White Burley*, *Nicotiana glutinosa* L., *Nicotiana tabacum* L. var. *German Samsun*, *Nicotiana rustica* L., *Nicotiana sylvestris* Spegaz and Comes, *Solanum nodiflorum* Jack., *Capsicum annuum* L., *Petunia hybrida* Vilm., *Lycopersicum esculentum* Mill. var. *Sutton's Early Market*. The reactions on these hosts gave an indication with regard to the presence or otherwise of virus. During this analysis the potato plant of *Majestic* variety proved to have been infected by a mixture of viruses. Solanum virus I was separated by passage through *Datura stramonium* which was found to be resistant to the other virus constituent. The second constituent was transmitted by juice inoculations to *Petunia hybrida* on which it showed vein clearing in early stages and later exhibited greening along the veins. On *Solanum nodiflorum* it developed veinal mosaic, showing that the constituent was *Solanum* Virus 2. Orton.

The culture of the virus thus isolated and purified was maintained on young tobacco plants of variety *White Burley* raised in sterile soil under insect proof conditions. Later on, transfers were made to a batch of young plants periodically in order to provide an inoculum from a stock of freshly infected plants throughout the course of the investigation. All plants were grown in 3 in.-4 in. clay pots. Standard extract for inoculation purposes was prepared by crushing to fine pulp in pestle and mortar a definite quantity of young infected leaves which had previously been washed several times in distilled water and dried in folds of filter paper, adding a small quantity of sterilized distilled water from time to time. To every gram of leafy material, 1 c.c. of water was added. This was then pressed through muslin by hand. The extract thus obtained was either used as such or filtered through filter paper as considered necessary for each experiment.

Inoculations were usually carried out on young tobacco plants of variety *White Burley* by smearing the leaf with a piece of sterilized absorbent cotton wool dipped in the standard extract of the culture to which a little carborundum powder had previously been added. Occasionally plants of *Nicotiana tabacum* were also used as indicators but for any one experiment the same variety of plants was used. This method usually gave 100 per cent infections. Checks were similarly treated except that extract from healthy plants was used as inoculum. Every care was taken to maintain aseptic conditions and all the apparatus used was sterilized in accordance with the needs of each experiment. Hands were thoroughly washed with lysol water and soap between each experiment.

The plants, as a rule, were inoculated when they developed the first 2-4 leaves and for any one experiment plants of the same age were employed so that the results could be strictly comparable. The inoculated plants were always kept under observation for at least 15 days.

The virus which has been described is defined by its reactions on the solanaceous plants. The reactions described are those observed during the months of December-March at Delhi in the presence of sufficient light and humidity.

Reactions on differential hosts

Nicotiana tabacum var. *White Burley*. Infection of this host is rapid and the symptoms often begin to appear two days after inoculation. The inoculated leaves first show faint mottle and later develop circular chlorotic spots which gradually become very distinct. Some of these spots may join and form a large chlorotic area. The infection soon becomes systemic and the younger leaves show small prominent chlorotic spots which are circular and some of which tend to be concentric. In youngest leaves the chlorotic spots sometimes develop necrotic centres. Later on all the old and young leaves show pronounced chlorotic ring spots. The symptoms in general are well pronounced (Plate VIII, fig. 1).

On variety *German Samsun* the first symptoms of infection are observed on the inoculated leaves about 5 to 6 days after inoculation. The leaves show either regular mottling of light with dark green or circular chlorotic spots. The symptoms are not marked.

The symptoms produced on *Nicotiana tabacum* are almost the same as produced on var. *White Burley*. Circular chlorotic spots appear on leaves 4-5 days after inoculation. On older leaves the spots are often well scattered over the whole surface and are in the form of characteristic rings. Later on the symptoms get more pronounced. (Plate VIII, fig. 2.)

Nicotiana glutinosa: Symptoms on inoculated leaves usually appear about six days after inoculation. Younger leaves show chlorotic spots

alongside the veins or on the veins or both. These spots later become very distinct and quite often join to form large irregular chlorotic areas. Older leaves also sometimes develop large circular chlorotic spots and some of these spots may develop necrotic centres.

Nicotiana rustica. Regular circular chlorotic spots begin to appear on inoculated leaves about 3-4 days after inoculation. These are surrounded by light green margin and often take the shape of concentric spots. The infection becomes systemic and in a few days typical concentric spots are observed on almost all the leaves (Plate VIII, fig. 3).

Nicotiana sylvestris. The symptoms begin to show a bout six days after inoculation. The first obvious symptom is the occurrence of light chlorotic spots on the inoculated leaves. Later when the infection becomes systemic the younger leaves also exhibit similar symptoms. The chlorotic spots are not concentric.

Datura stramonium. In 4-5 days after inoculation the leaves first exhibit light mottling which develops into distinct circular chlorotic spots. These spots cover the entire surface of the leaf. About four days later vein-clearing is observed on the younger leaves. At the same time some of the middle leaves also show vein-clearing near the basal region which gradually spreads upwards and eventually covers the entire surface. Sometimes chlorotic spots are also observed on the young leaves. Young leaves which show vein-clearing later develop severe chlorosis between the veins along which a deep green portion persists. This symptom is more pronounced at the basal portion of leaves. Older leaves continue to show faint chlorotic or pale spots. Some leaves even develop necrotic lesions (Plate IX, figs. 1-A and 1-B).

Solanum nodiflorum. In about five days after inoculation light but distinct mottle appears on inoculated leaves. Circular chlorotic spots also develop near or along the veins.

Capsicum annuum. First symptoms of infection in the form of light mottle appear on younger leaves about eight days after inoculation. Older leaves show circular pale spots. Later, the mottling may become more pronounced.

Lycopersicum esculentum. Variety *Sutton's Early Market.* Within 5-6 days after inoculation light green—dark green mottling appears on leaves. The mottle is usually interveinal. There is neither apparent reduction in the size of leaves nor any distortion. About four days later the symptoms become more distinct (Plate IX, fig. 2).

Efforts to transmit the disease to *Petunia hybrida* Vilm. and *Lagenaria vulgaris* Ser., by inoculations with the standard extract were unsuccessful. Immunity of *petunia hybrida* was further confirmed by back inoculation to tobacco.

Reactions on differential hosts of other cultures of *Solanum Virus* I recovered from a large number of plants of *Phulwa variety* showing varying degrees of mottle were also noted. In addition, reactions on differential hosts of several other cultures obtained from plants of *Darjeeling Red Round*, *Gola* and *Windsor Castle* varieties were studied. Typical symptoms observed are summarized in Table I.

The data given in Table I show that on the basis of reactions on differential hosts the cultures fall into four distinct groups. The first one in which the symptoms produced are in general very faint. This includes culture numbers 1, 2, 5, 6, 7, 8 and 9.

The second group in which the symptoms produced are definite and on some hosts well pronounced. This includes culture numbers 3 and 4.

The third group in which the symptoms produced are highly pronounced and in some cases may even show necrotic lesions. This includes culture numbers 10 and 11.

The fourth group in which the symptoms exhibited on the differential hosts are extremely severe, i.e. resulting in general necrosis and even collapse of leaves (Plate IX, fig. 3). This includes culture number 12.

Properties of the virus

Properties of the culture recovered from plant of *Majestic* Variety and which falls in the third group are described below:

(i) *Thermal-death-point.* Standard extract prepared from young infected tobacco plants was divided into six samples of 3 c.c. each in thin walled glass test tubes of uniform size and capacity. Samples of the standard extract in tubes were exposed to 50°, 60°, 70°, 75°, 80° and 90°C. for ten minutes in a water bath. Every care was taken that the portion of the tube containing the infected plant extract was completely immersed in water. The samples of extract soon after exposure at different temperatures were dipped in cold tap water. Young tobacco plants were inoculated with the samples of standard extract thus exposed and with untreated extract which served as control. The experiment was repeated with the standard extract which had been previously filtered through filter paper. The results of two typical experiments are given in Table II.

FIG. 1. Leaf of infected tobacco var. White Burley, showing circular chlorotic spots

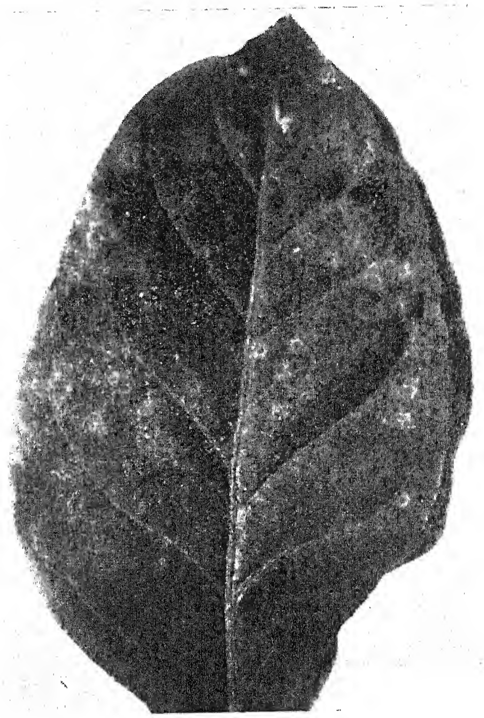

FIG. 2. Leaf of infected *Nicotiana tabacum* showing chlorotic as well as some ring spots

FIG. 3. Leaf of infected *Nicotiana rustica* showing typical concentric spots

[*Indian J. agric. Sci.*, Vol. 14, Part IV

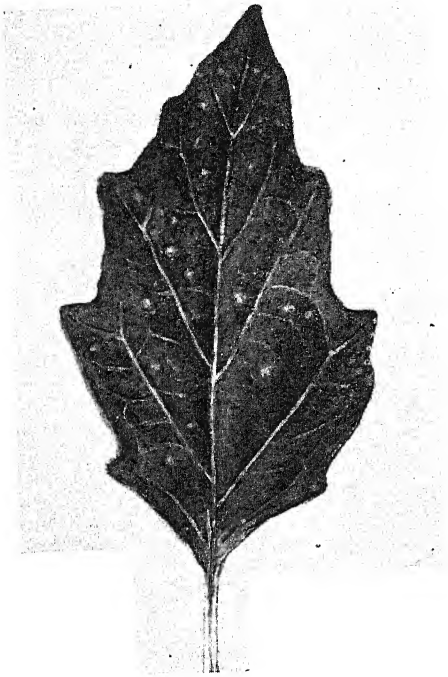

FIG. 1–A. Leaf of infected *Datura stramonium* showing early symptoms of infection

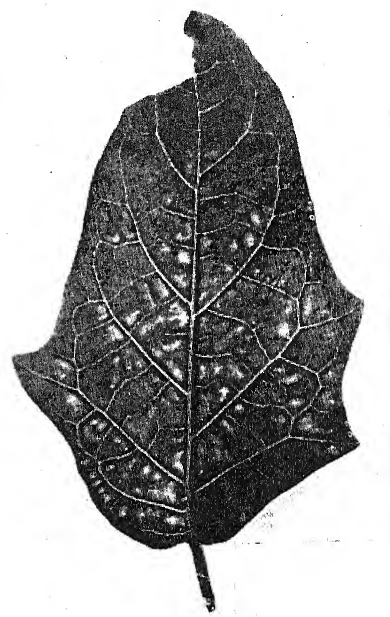

FIG. 1–B. Leaf of infected *Datura stramonium* showing intense chlorosis between the veins–A later stage of infection

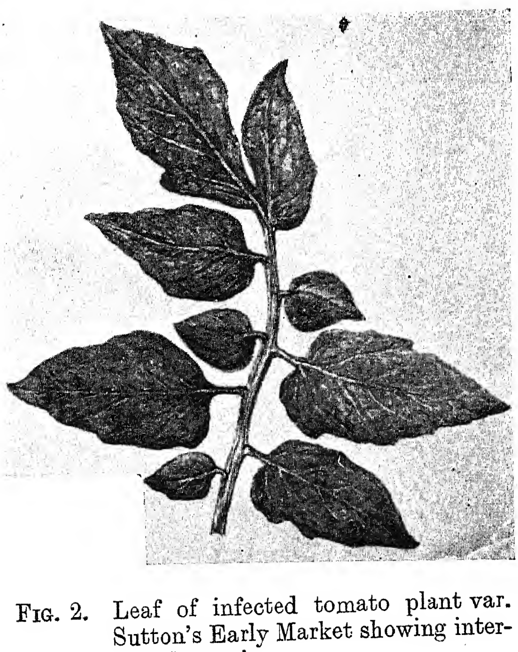

FIG. 2. Leaf of infected tomato plant var. Sutton's Early Market showing interveinal mosaic

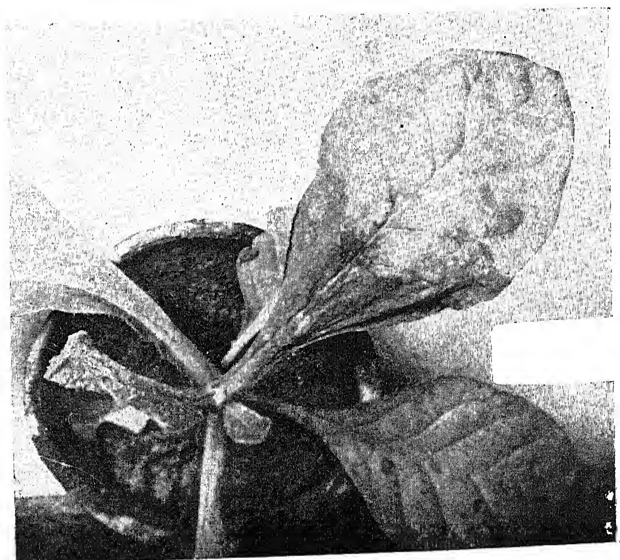

FIG. 3. A plant of *Nicotiana tabacum* infected with *Solanum* Virus I (group 4 from potato variety Windsor Castle) showing general necrosis and collapse of leaves

TABLE I

Reactions of certain typical cultures on differential hosts

Culture No.	Source	*Tobacco* var. *White Burley*	*Nicotiana tabacum*	*Nicotiana glutinosa*	*Datura stramonium*	*Capsicum annuum*	*Solanum nodiflorum*	*Petunia hybrida*	*Lycopersicum esculentum* var. *Sutton's early market*
1	Potato var. *Phulwa*	Light mottle with circular chlorotic spots	Light mottle with circular chlorotic spots	Light mottle and circular chlorotic spots	Light but definite mottle tending to disappear after a week	No clear symptoms	No clear symptoms	No symptoms	...
2	*Phulwa* .	Faint mottle and circular chlorotic spots	Faint mottle and circular chlorotic spots	Circular chlorotic spots. A few concentric spots also present	Fleeting mottle .	Faint mottle .	Small circular chlorotic flecks	Do.	Small circular chlorotic flecks on younger leaves
3	*Phulwa* .	Young leaves show distinct circular chlorotic spots which, with an advance in age, develop brown centres. Older leaves show circular chlorotic spots mainly near the veins and a few concentric spots	Distinct circular chlorotic spots on young leaves. Old leaves show mottle or circular chlorotic spots	Circular chlorotic spots on younger leaves along the veins	Light mottle on young leaves	Faint mottle .	Circular chlorotic flecks on young leaves	Do.	Chlorotic flecks on young leaves. Also faint interveinal mosaic
4	*Phulwa* .	Young leaves show very distinct circular chlorotic spots. Older leaves show circular chlorotic or pale spots as well as concentric spots. In a later stage some chlorotic spots develop necrotic centres	Circular chlorotic spots on young leaves. Later faint mottle and concentric spots on older leaves	Circular chlorotic spots on young leaves	Light but distinct mottle	Light mottle on younger leaves	Chlorotic flecks on younger leaves. Older leaves show light mottle	Do.	Distinct mottle and circular chlorotic flecks on young leaves, which later develop interveinal mosaic
5	*Phulwa* .	Young leaves show circular chlorotic spots. Older leaves show light mottle	Younger leaves show circular chlorotic spots. Older leaves show faint mottle and some faint ring spots	Younger leaves show circular chlorotic spots. Older leaves show faint mottle	Light but distinct mottle	Faint mottle	Circular chlorotic flecks on younger leaves	Do.	Mottle and circular chlorotic flecks on young leaves which later develop light interveinal mosaic
6	*Phulwa* .	Circular chlorotic spots on young leaves. Older leaves show faint mottle	Faint circular chlorotic spots on younger leaves	Circular chlorotic spots on younger leaves generally along the veins	Very light mottle .	...	Distinct chlorotic flecks particularly along the veins	Do.	No clear symptoms
7	*Phulwa* .	Circular chlorotic spots on young leaves. Older leaves show light mottle	Circular chlorotic spots on younger leaves	Circular chlorotic spots particularly along the veins	Faint mottle .	Distinct chlorotic spots on young leaves	Faint chlorotic flecks	Do.	Light mottle and chlorotic flecks

TABLE I—*contd.*

Culture No.	Source	*Tobacco* var. *White Burley*	*Nicotiana tabacum*	*Nicotiana glutinosa*	*Datura stramonium*	*Capsicum annuum*	*S lanum nodiflorum*	*Petunia hybrida*	*Lycopersicum escalentam* var. *Sutton's early market*
8	*Darjeeling Red Round*	Small circular chlorotic spots	Faint mottle	Faint chlorotic spots on young and faint mottle on old leaves	Very faint mottle which disappears within five days	A few light green or faint chlorotic areas near the veins	No clear symptoms	Do.	...
9	*Darjeelin, RedRound*	Circular chlorotic spots	Light mottle and circular chlorotic spots	Light mottle and circular chlorotic spots	Very faint mottle	No clear symptoms	Faint circular chlorotic spots on some leaves	Do.	...
10	*Majestic*	Very distinct circular chlorotic spots on young leaves. Older leaves develop pronounced cricular pale or chlorotic spots, which later appear as ring spots. Some chlorotic spots may develop necrosis	Symptoms same as in *white Burley*	Very distinct circular chlorotic spots on or along the veins. Some of these spots develop necrosis	Very distinct circular chlorotic spots. Later vein clearing of younger leaves which develop into intense chlorosis between the veins. Some of the chlorotic spots develop necrosis	Distinct chlorotic spots	Distinct circular chlorotic spots	Do.	Distinct interveinal mosaic
11	*Gola*	Distinct circular chlorotic spots some of which later develop necrosis	Distinct circ ular chlorotic spots some of which later develop necrosis	Distinct circular chlorotic spots some of which later develop necrosis	Distinct circular chlorotic spots. Later young leaves show vein clearing which develops into intense chlorosis between the veins	...	Circular chlorotic flecks particularly along the veins	Do.	Light mottle and chlorotic flecks
12	*Windsor Castle*	......	Very distinct circular chlorotic spots on all leaves later turning into concentric spots. Finally leaves collapse due to severe necrosis	Distinct circular chlorotic spots. Development of necrosis at a later stage	Chl orotic spots on older leaves. Younger leaves show vein clearing which develops into chlorosis between the veins. Leaves finally develop necrosis	...	First distinct chlorotic flecks and later prominent circular chlorotic spots. Some spots develop necrosis	Do.	Chlorotic flecks, later general, mosaic mottle. Leaves finally develop severe necrotic lesions

TABLE II

Thermal inactivation of the virus

Exposure—Temperture °C.	Experiment I Number of plants		Experiment II Number of plants	
	Inoculated	Infected	Inoculated	Infected
Unheated control	2	2	3	3
50	3	3	—	—
60	3	3	3	3
65	—	—	3	2
70	3	1	3	1
75	—	—	3	0
80	3	0	3	0
90	3	0	—	—

—denotes not tested

The results given above show that the activity of the virus appreciably falls when exposed to 70°C. and that the virus is completely inactivated at 75°C. or higher. In the plants inoculated with the extract exposed to 75°, 80°, and 90°C., no symptoms of infection were observed even after three weeks.

(*ii*) *Dilution end point.* In order to determine the effect of dilution on infectivity, leaves of young tobacco plants of variety *White Burley* were inoculated with unfiltered freshly extracted pure juice from infected tobacco leaves as well as with juice diluted with sterilized distilled water. Inoculations were also made with standard extract. The experiment was repeated several times and both filtered through filter paper and unfiltered freshly extracted pure juice were tested. The results of one lot of experiments are given in Table III.

TABLE III

Effect of dilution on infectivity

Dilution	Set I Number of plants		Set II Number of plants		Set III Number of plants	
	Inoculated	In fected	Inoculated	Infected	Inoculated	Infected
Nil (pure extract)	4	4	3	3	3	3
Standard extract	3	3	—	—	—	—
1 : 100	3	3	—	—	—	—
1 : 500	3	3	—	—	—	—
1 : 1000	3	3	2	2	3	3
1 : 5000	3	3	—	—	—	—
1 ; 10,000	3	3	2	2	3	2
1 : 12,000	3	3	—	—	—	—
1 : 15,000	3	3	2	2	—	—
1 : 20,000	—	—	3	3	3	1
1 : 30,000	—	—	3	3	—	—
1 : 40,000	—	—	3	3	3	1
1 i 80,000	—	—	—	—	3	1
1 : 100,000	—	—	—	—	3	0

—denotes not tested

The results recorded above indicate that the virus begins to lose its infectivity at a dilution of 1 : 40,000 and is inactivated at 1 : 100,000. In one of the experiments one of the test plants showed faint symptoms of infection even at a dilution of 1 : 100,000, showing that at times it may withstand a dilution up to 1 : 100,000. In dilutions of 1 : 100 to 1 : 10,000 the symptom expression on the test plants was similar and almost of the same intensity as produced by pure and standard extracts.

(*iii*) *Filterability.* Standard extract prepared from young infected tobacco leaves was filtered through filter paper, filter paper impregnated with diatom dust and Pasteur Chamberland filters of grades L_3 and L_5. Prior to passing the standard extract through Chamberland filters it was passed through filter paper impregnated with diatom dust in order to remove as much as possible of the leafy material which tends to clog the filter. All the candles before use were always tested for bubbling pressure and the filtrations were carried out under reduced pressure of 1/5 atmospheric Infectivity of the filtrates was tested on young *White Burley* tobacco plants in the inect proof house. The results of a typcal experiment are given in Table IV.

The results show that the virus passes through all the filters tested and that its activity is not impaired during passage through the filters.

(*iv*) *Longevity in vitro.* Ampoules were filled with L_3 filterate of standard extract which had

TABLE IV

Filterability of the virus

Expt.	Inoculum	Date of inoculation	No. of plants inoculated	Date of infection	No. of plants infected
I	1. Unfiltered standard extract	24-3-43	2	26-3-43	2
	2. Chamberland candle L_3 filtrate	24-3-43	2	26-3-43	2
II	1. Unfiltered standard extract	25-3-43	3	27-3-43	3
	2. Filtered standard extract				
	(*a*) Filter paper (Whatman No. 1) filtrate	25-3-43	3	27-3-43	3
	(*b*) Filter paper impregnated with diatom dust filtrate	25-3-43	3	27-3-43	3
	(*c*) Chamberland candle L_3 filtrate	25-3-43	4	27-3-43	4
	(*d*) Chamberland candle L_5 filtrate	25-3-43	4	27-3-43	4

been freshly prepared from infected tobacco leaves. All precautions were taken to fill the ampoules under aseptic conditions. The ampoules containing the filtered standard extract were stored in a cool cabinet where the temperature varied from 14° to 17°C. and young *White Burley* tobacco plants were inoculated with samples of stored filtrate at various intervals. The fresh filtrate was tested for its infectivity prior to storage.

Results of such an experiment are given in Table V.

The results recorded above show that the activity of the standard extract is not impaired even after being stored for 202 days but the activity falls considerably after storage for 234 days.

TABLE V

Effect of storage of virus

Storage period	No. of plants	
	Inoculated	Infected
Fresh extract	2	2
17 days	3	3
34 days	4	3
46 days	3	2
81 days	3	3
202 days	3	3
234 days	6	1

In another experiment unfiltered standard extract from nfected tobacco plants was stored at room temperature (26·6°-31·1°C.) and it was observed that the extract stored for different periods up to 96 hours proved 100 per cent infectious.

(*v*) *Effect of drying*. 5 c.c. of unfiltered standard extract prepared from infected tobacco leaves was left to dry in a large watch glass at room temperature which varied from 26·6° to 31·1°C. After 10 days when the extract had dried up, 5 c.c. of sterile distilled water was added to make up to the original volume. Three young *White Burley* tobacco plants were inoculated to test the infectivity of the material. Only one of the inoculated plants showed faint symptoms of infection. In another similar experiment filter paper filtrate of standard extract was tested and only three plants out of five showed signs of infection after five days.

The results indicate that the infectivity of the standard extract is greatly impaired but not lost after being dried at room temperature.

(*vi*) *Immunological relationship*. Tobacco plants already infected with a known weak strain of *Solanum virus* I were inoculated with the standard extract obtained from young infected tobacco plants. The second inoculum was introduced 15 days after inoculation with the weak strain in order to give sufficient time for the dissemination of this strain throughout the plant. Also healthy plants were inoculated to serve as check. The plants already infected with a weak strain of *Solanum virus* I continued to exhibit the characteristic faint symptoms of the weak strain but the control plants developed typical pronounced symptoms of infection, showing that the weak strain had immunized the plants against infection by the more virulent strain of the virus.

(*vii*) *Resistance to chemicals*. Effect of absolute alcohol and ether on the standard extract prepared from young infected *White Burley* tobacco plants was determined by exposing 3 c.c. of the

extract in watch glasses of 2·75 in. diameter to vapours of alcohol and ether in desiccators. The watch glasses containing the extract were removed at regular intervals and the infectivity of the treated extract tested on young tobacco plants. The results of such an experiment are given in Table VI.

The results show that the virus is inactivated after 12 hours' and 32 hours' exposure to vapours of absolute alcohol and ether respectively.

The symptoms on differential hosts and the properties of the virus described show that it is a strain of *Solanum virus* I which resembles, in certain respects, such as dilution end point, strain X^N of Salaman [1938]. The symptoms on the differential hosts are not so pronounced as those described for X^N.

TABLE VI

Effect of alcohol and ether on the activity of the virus

Period of exposure (hours)	Alcohol		Ether	
	No. of plants		No. of plants	
	Inoculated	Infected	Inoculated	Infected
Untreated standard extract	3	3	3	3
4 . . .	3	2	3	3
8 . . .	3	2	3	2
12 . . .	3	0	3	1
24 . . .	3	0	3	2
32 . . .	3	0	3	0

SUMMARY

Properties and reactions on differential hosts of a comparatively virulent strain of *Solanum virus* I isolated from *Majestic* variety of potatoes are described.

The virus loses infectivity at a dilution of 1 : 100,000 and exposure to 75°C., for 10 min. is sufficient to destroy the active principle. The virus passes through Chamberland filters of grade L_3 and L_5 without any deleterious effect on its activity. Storage of the virus for 234 days does not render it innocuous.

Reactions on differential hosts of several other cultures of *Solanum virus* I have been studied and the cultures have been divided into four groups on this basis.

ACKNOWLEDGEMENT

Thanks are due to Dr G. Watts Padwick, Imperial Mycologist, for much helpful criticism and interest during the course of this investigation.

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STUDIES ON THE JUTE STEM-WEEVIL *APION CORCHORI* MARSHALL

I. BIONOMICS AND LIFE-HISTORY

By G. M. DAS, Jute Agricultural Research Laboratories, Dacca

(Received for publication on 28 April 1944)

(With Plate X and four text-figures)

APION corchori Marshall, a stem-borer of jute and commonly known as *jute Apion*, damages the fibre and lowers its quality. Lefroy [1906; 1907 and 1909] was the first to record a species of *Apion* breeding in the stem of jute. He regarded it as a minor pest, but visualized the possibility of its causing serious damage. At the Entomological meetings held at Pusa in 1917 and 1919, the consensus of opinion was that it is a minor pest but sporadically serious. In view of this it is not surprizing that the species was not named till in 1936.

Since *Apion* is minute in size and the damage caused by it is not conspicuous, the attention of cultivators has never been focussed on it. In the author's opinion, it is a major pest of jute.

Distribution

The pest is common in Assam, Bihar, Orissa and Bengal. It is wide spread in all the jute-growing districts of Bengal. In Madras, Fletcher [1914] reported it from Bellary and Godavary, and Krishna Ayyar [1940] from Coimbatore.

Nature of damage

The female weevil bores a hole with its rostrum on the stem near the apex of the plant. The egg is generally deposited in between the vascular bundles which are still distinct from one another. In this process the epidermis, cortex, starch sheath and phloem are pierced (Plate X, fig. 4). Very often the cambium itself is injured, and as a result, further development of fibres and wood near the place of injury is checked.

The grub, on hatching, starts feeding on the surrounding tissues and generally tunnels into the pith damaging the fibre. In the pith it may travel up or down for considerable distance, filling the rear of the tunnel with frass. Where the tunnelling is extensive (Plate X, fig. 6) the shoot above withers and numerous side branches are produced. Such plants are undesirable as they yield short fibre. The injury done to seedlings is serious. If they are attacked below the cotyledonary leaves, they die outright. The older plants survive the attack, but remain stunted when attacked repeatedly. Pods are also liable to damage as they are occasionally selected for oviposition.

The place of injury can easily be recognized by the swollen appearance (caused by the abnormal growth of cortical cells, Plate X, fig. 5), and the dark discolouration of the stem or by the withered shoot and axillary bud. Where the epidermis is eaten up, even the excreta may sometimes be seen.

A transverse section passing through the place of injury (Plate X, fig. 5) shows that the mucilaginous substance which oozes out as a result of *Apion* damage firmly binds or cements the adjacent tissues together with the weevils excreta into a hard structure which greatly resists retting. Further, the plant in an attempt to localize injury develops wound cork all around the damaged tissues. This wound cork being suberized also resists retting with the result that at the place of damage the fibre and adjacent tissues are cemented together forming a *knot* (Plate X, figs. 3 and 7). Even after retting, the excreta of *Apion* grub, abnormal cortical cells, epidermis, periderm, fibre bundles and intervening phloem cells are found to form a single compact mass.

Late in the season, ovipositon is generally restricted to the basal part of the stem and the whole bark is found riddled by the grubs, resulting in a hard compact mass with the bark sticking to the fibre. This damage has in the past been described either as specky or knotty, but the term knotty should be restricted to fibre having knots caused by *Apion* injury, while the term specky be used for fibre having fragments of bark adhering to it. A sort of knot may be formed at the nodes due to the leaf and branch traces [Patel, 1943], but the knot caused by *Apion* injury can easily be distinguished by the presence of excreta.

In trade, knots constitute an important defect in fibre quality. These form needles in the sliver and cause breaks in the yarn during spinning, winding and weaving. To the cultivators this defect is known as ‘ gira ’ or ‘ chouk ’, but most of them do not associate it with this tiny weevil.

Life-history of various stages

Pre-oviposition period. As the weevils are almost sexually mature at emergence, the pre-copulation and pre-oviposition periods are rather short. The copulation starts within a day or two after emergence, and is repeated several times a day throughout the season. In ten cultures bred in the laboratory in 1941, the pre-oviposition period varied from 5 to 9 days, the most common being 5 days. In 1942 the pre-oviposition period ranged from 3 to 8 days in fifteen such cultures (Table I). In rare instances, it may extend up to 22 days.

Oviposition. The mode of selection of site for and the process of oviposition are almost similar to those in the cotton-stem weevil, *Pempherulus affinis* [Krishna Ayyar and Margabandhu, 1941]. The female weevil selects for oviposition a place on the stem near the base of petiole and not very far away from the top. Standing on the petiole, it bores a hole with the rostrum, turns back and then deposits the egg in the hole. Only one egg is laid in each hole and the mouth of the hole is sealed with dark excreta. Occasionally more than one hole can be seen in the same neighbourhood but the egg is found only in one hole. Other holes presumably are not suitable for oviposition. Rarely, eggs are laid in the petiole or in the pod. From the middle of July onwards, the eggs are mostly laid in the basal part of the stem. The tops are then rarely attacked. In low-lying areas, where the basal parts of the plants remain under flood water, the weevils have no alternative but to lay eggs in the upper region.

Under laboratory conditions the oviposition period ranged from 6 to 124 days, the maximum

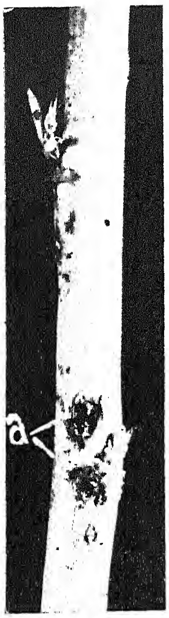


FIG. 1.

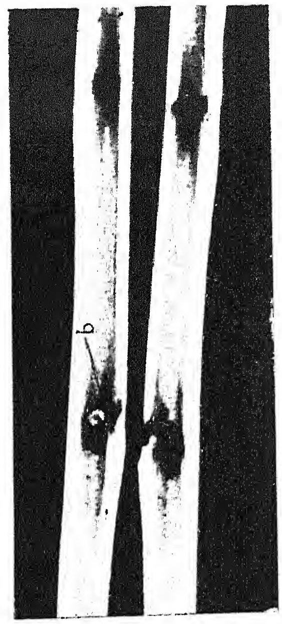


FIG. 2.

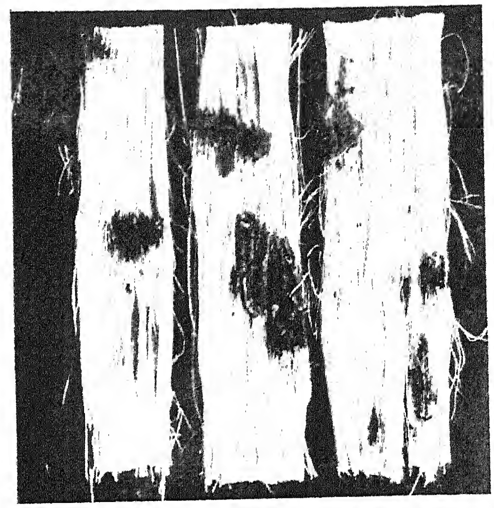


FIG. 3.

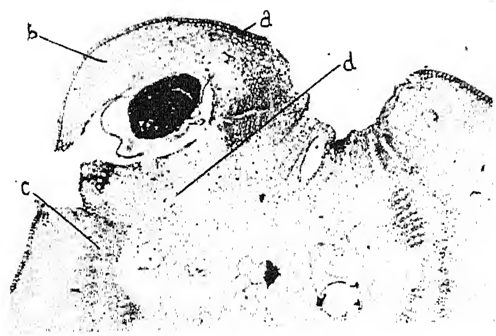


FIG. 4.

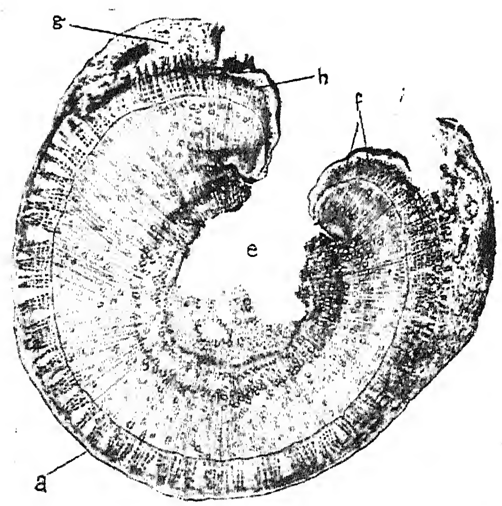


FIG. 5.

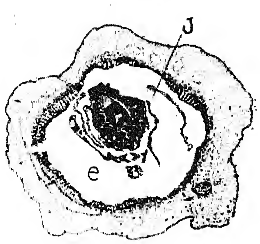


FIG. 6.

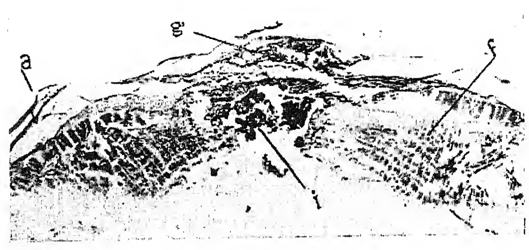


FIG. 7.

TABLE I

Oviposition record

Date of emergence	Date of first oviposition	Number of eggs laid								Total No. of eggs laid	Pre-oviposition period (days)	Oviposition period (days)	Average No. of eggs laid per day
		May	June	July	August	September	October	November	December				
17-7-41	23-7-41	..	..	27	..	..	..	..	..	27	6	6	4·5
18-7-41	Do.	..	..	38	183	89	..	..	..	310	5	61	5·1
Do.	Do.	..	..	67	110	..	..	..	..	177	5	33	5·4
Do.	Do.	..	..	68	58	..	..	..	..	126	5	19	6·6
Do.	Do.	..	..	58	158	136	38	..	..	390	5	81	4·8
Do.	27-7-41	..	..	35	187	18	..	..	..	240	9	40	6·0
16-8-41	22-8-41	..	..	..	61	144	107	14	..	326	6	76	4·3
21-8-41	26-8-41	..	..	..	11	157	101	19	..	288	5	75	3·8
24-8-41	2-9-41	..	..	..	..	119	108	50	17	294	9	101	2·7
3-9-41	10-9-41	..	..	..	..	98	109	12	..	219	7	61	3·6
6-5-42	11-5-42	121	191	127	..	..	..	..	..	439	5	68	6·5
24-5-42	28-5-42	27	178	190	..	..	..	..	..	395	4	65	6·1
Do	1-6-42	..	212	187	116	21	..	..	..	536	8	98	5·8
26-5-42	29-5-42	10	226	201	140	41	..	..	..	618	3	109	5·7
Do	1-6-42	..	196	194	113	8	..	..	..	511	6	94	5·4
26-5-42	Do	..	238	186	71	..	..	..	..	495	6	74	6·7
28-5-42	Do	..	175	183	152	149	16	..	..	675	4	124	5·4
21-6-42	26-6-42	..	28	210	170	134	36	..	..	578	5	106	5·5
23-6-42	Do	..	29	176	127	146	34	..	..	512	3	103	5·0
13-7-42	16-7-42	..	..	90	126	152	10	..	..	378	3	79	4·8
14-7-42	17-7-42	..	..	69	123	127	45	..	..	364	3	69	5·0
16-8-42	19-8-42	..	..	..	76	159	109	..	..	344	3	85	4·1
24-9-42	30-9-42	..	..	..	..	1	117	76	9	203	6	69	2·9
Do	Do	..	..	..	..	1	109	57	4	171	6	65	2·6
15-10-42	20-10-42	..	..	..	..	..	60	69	11	140	5	51	2·7

number of eggs laid being 675 during 124 days. The highest number of eggs laid in a day was 13. The average egg-laying varied from 2·6 to 6·7 per day.

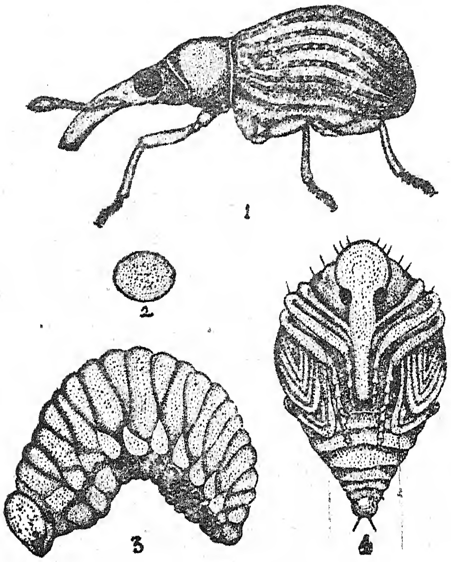
From Table I it is evident that the weevils that emerged in August laid on an average lesser number of eggs than those emerging in July. Irrespective of early or late emergence of the weevil, the egg laying potentiality appears to become reduced towards the end of the jute season, and by December egg-laying practically ceases. The weevils emerging late in season are rarely seen to oviposit soon after.

Incubation period. In the middle of jute season, i.e. in June and July, the incubation within the stem occupies three days at room temperature of 84°-86°F. In a partially dried up stem, it is prolonged to four days. In January when the average mean temperature was 71·9°F., the eggs hatched in five days.

In nature the eggs are deposited in direct contact with the cell sap and are thus protected from desiccation. Freshly laid eggs removed from the stem and left naked in tubes did not hatch either at room temperature or at a constant temperature of 32°C. When, however, the eggs were kept in an atmosphere fully saturated with moisture (with accumulation of fine particles of water in direct contact with eggs), they readily hatched at room temperature or at a constant temperature of 32°C. The eggs could easily be hatched in agar agar media.* Ahmad [1939] observed that the eggs of *Lixus truncatulus* required for their development not only a saturated atmosphere, but perhaps direct contact with free water.

Egg. The egg (Fig. 2) is small, oblong and broadly rounded at both ends. On an average it measures 0·43 mm. in length and 0·33 mm. in breadth. It is white with glistening surface. As it develops it swells up slightly. The brown mandibles of the embryo become visible after two

*2 gm. of agar agar in 100 c.c. of water or jute stem extract



FIGS. 1—4. *Apion corchori* Marshall
1. Adult female (× 19); 2. Egg (× 18);
3. Full grown grub (× 16); and 4. Pupa (× 18)

days. Before hatching the mandibles are seen to work slowly and the young grub comes out through a slit.

Grub. A freshly hatched grub is slightly longer than the egg. The full-grown grub (Fig. 3) measures on an average 2·85 mm. in length and 0·98 mm. in breadth. The head capsule is small and light brown in colour. The mandibles are dark brown. The body is uniformly light yellow, and well curved, the middle segments being slightly bigger. The terminal segment is broadly rounded at its posterior end.

The mouth-parts of the grub are of usual biting and chewing type, and quite similar to those of *Calandra granaria* [Das, 1939]. The labrum is elliptical with a slight notch at its anterior margin. Each mandible is strongly sclerotized having a broad triangular base, a mesal surface which is produced into two incisor lobes, and a molar or crushing surface near the base. Each maxilla consists of an undivided cardo, a stipes and a two-segmented palpus. The lacinia is present but the galea is totally absent. The labium consists of a membranous postmentum, and a prementum bearing two small two-segmented palpi and a middle lobe.

The grub stage is extremely variable and occupies 8 to 18 days under laboratory conditions. Variation in the larval period might be due to the state of the stem, whether fresh, partially or wholly dry. A similar observation has been made by Krishna Ayyar and Margabandhu [1941] in the cotton-stem weevil, *Pempherulus affinis*, in which a lengthened emergence of weevils is brought about by uneven

TABLE II

Larval period § at room temperature (78°-90°F.)

Number	Date of hatching	Date of pupation	Larval period (days)
1	8 June .	20 June .	12
2	17 June .	25 June .	8
3	20 June .	29 June .	9
4	23 June .	6 July .	13
5	25 June .	9 July .	14
6	29 June .	11 July .	12
7	3 July .	14 July .	11
8	5 July .	15 Juy .	10
9	6 July .	24 July .	18
10	8 July .	23 July .	15

§ Only a cross-section of the entire data

development of the mature grubs, owing to either insufficient nutrition or extreme dryness or dampness of the stem.

Pupa. When full-fed, the grub makes a rough chamber of excreta inside the stem and pupates within it. Before pupation the abdomen of the grub becomes straight and the prepupa looks longer than the grub. The pupa (Fig. 4) measures about 2·07 mm. in length and 1·08 mm. at its maximum width. The body is pale yellow gradually turning light brown. The eyes are reddish brown in the beginning but afterwards they turn black. The wing pads lie between the second and third pairs of legs, and extend beyond the abdomen. The abdomen is slightly curved. The rostrum lies ventrally. The legs are folded and the antennæ run parallel to the tibiæ.

The duration of the pupal period inside the stem at room temperature of 84°-85°F. is about four days, but when the pupa is left naked, the pupal period is slightly shortened. The adult weevil emerges through the passage previously made by the grub during feeding, or by making a fresh hole.

The whole life cycle from egg up to emergence of the adult is completed in 15 to 25 days.

Adult. It is a small tiny weevil (Fig. 1), about 1·8 mm. in length and 0·8 mm. in breadth, with the curved snout very conspicucous. It is dark brown or dull black clothed with sparse whitish setæ almost throughout the body. The female is slightly bigger than the male. The detailed description of the weevil has been given by Marshall [1936].

Longevity. The life of the weevil is fairly long. The maximum age recorded under captivity was 209 days and the minimum 11 days. The average for 153 weevils was 81 days (Table III).

TABLE III

Longevity of weevils

Number of weevils observed	Maximum life (days)	Average life (days)	Weevils emerged on
10	121	65·9	17-6-41
10	108	53·4	28-6-41
12	190	106·3	16-7-41
13	209	120·2	16-7-41
10	162	62·9	19-9-41
10	119	75·9	4-11-41
15	119	97·4	15-11-41
10	98	66·8	1-6-42
10	112	66·2	14-6-42
10	117	65·1	15-7-42
10	121	69·7	21-9-42
12	153	97·2	24-9-42
10	116	102·9	2-10-42
11	127	63·8	1-11-42
			Old weevils collected on
10	76	45·2	2-5-41
10	75	45·5	3-5-41
16	93	71·1	1-5-42
20	123	78·3	1-5-42

NUMBER OF BROODS AND SEASONAL HISTORY

There is much overlapping of the rapidly succeeding broods and the crop is heavily infested with all stages. The weevils emerge throughout the crop season without any break. The overwintering weevils breed for about two months and a half. Excepting those emerging in November all weevils breed in the same season, but the breeding activity declines as the jute season advances.

The weevils can be seen on the crop throughout the jute season, and their presence can be detected by small pin-holes made on tender leaves during feeding. They drop on the ground at slight disturbance and feign death. The weevils have been observed to attack self-sown plants as early as in January. In low lying areas where self-sowing does not occur, the weevils have been seen on very young seedlings about 2 in. in height by the middle of March.

As immediately after the harvest of jute the immature stages are found in the stubbles, it was thought that either the grubs or pupæ might pass the winter in hibernation in the stubbles, or in soil around the stubbles. Examination of stubbles and surrounding soil carried out during the winter failed to reveal the presence of any immature stages of the pest. Under laboratory conditions at a temperature of 71°-78°F. and mean relative humidity of 86 per cent the grubs in the stubbles did not enter the soil for pupation, but pupated in the stubbles and emerged as weevils, during the later part of November ; neither the larval period nor the pupal period was prolonged.

The adult weevils pass the winter in concealment in bushes, shrubs and hedges. *Streblus asper* Lour, *Glycosmis pentaphylla* Corr., var. *nitida*, *Ziziphus eonoplia* Mill, *Blumea lacera* D.C., *Pithecolobium dulce* Benth, *Hibiscus rosa-sinensis* Linn., *Gossypium spp.*, *Duranta plumieri*, and Guinea grass (*Panicum maximum* Jacq.) are seen to afford shelter to the weevils during the off season, but the insect was never found to breed on them. On any of these plants, the weevils did not feed in the laboratory. When supplied with water the weevils lived without food up to a maximum of 35 days. It may be that under natural conditions they can live for a longer period without food and these conditions could not be reproduced in the laboratory.

Alternate host. Intensive search has so far revealed only one alternate host, viz. *Triumfetta rhomboidea* Jacy, locally known as *bun-okra*, a fibrous weed belonging to the family *Tiliacae.* It is widely distributed throughout tropical and, sub-tropical regions of India and Ceylon, ascending up to 4,000 ft. in the Himalayas.

The weevils feed on the leaves of this plant and occasionally breed in the stem. In winter the grubs and pupæ have been collected from the infested stems of *bun-okra*. In feeding experiments with jute and *bun-okra* leaves, the weevils did not show any preference. During the season *bun-okra* plants growing near the jute fields are found less infested than jute. The stems of *bun-okra* are not so soft and succulent and may not be so suitable as those of jute for the development of the grubs. Krishna Ayyar [1940] reports *Triumfetta rhomboidea* as an alternate host of the cotton-stem weevil (*Pempherulus affinis* Fst.) which also occasionally breeds in the stem of jute (*C. olitorius*).

VARIETAL SUSCEPTIBILITY

Five species of *Corchorus* have been under observation for three seasons. *C. acutangulus* in spite of the presence of long hairs on the leaf, petiole and stem is highly susceptible to *Apion* attack. *C. trilocularis* and *C. fascicularis* are less susceptible than *C. acutangulus*. All the above three are wild species of jute.

Among the two cultivated species, *C. olitorius* is less susceptible than *C. capsularis*. The following records taken from botanical trials conducted in the same field show that *capsularis* varieties are in general more susceptible than *olitorius* ones, though in certain years the difference between the two species may become negligible.

With a view to assessing varietal resistance a trial of 49 types was carried out in the years 1939, 1940 and 1942. The variation in susceptibility to *Apion* attack was found to be limited in the case of *olitorius* varieties, whereas the *capsularis*

TABLE IV

Infested plants per cent

	1939	1940	1942
Olitorius varieties			
R. 26	13·8	65·3	93·3
C. G.	17·2	59·3	98·7
Dacca local	23·1	61·0	99·0
Critical difference	7·2	Insignificant	3·4
Capsularis varieties			
D. 154	57·4	82·1	98·7
Fanduk	59·7	78·2	95·7
D. 386	65·2	78·7	98.0
Critical difference	Insignificant	Insignificant	2·2

varieties exhibited rather a wider range. The resistance of *olitorius* may possibly be due to its higher tannin content, which is about three times more than in *capsularis* stems. In feeding experiments the weevils preferred *capsularis* leaves (which are found to contain less tannin) to *olitorius* ones.

EXTENT AND INTENSITY OF INFESTATION

Assessment of damage. In gauging the damage, the percentage of infested plants as well as the number of punctures in such plants are important. From Table V it is evident that about 50 per cent of *capsularis* plants were attacked three times or more, whereas in *olitorius* only 17 per cent of the plants had three or more punctures. In general, the greater the number of plants infested, the higher was the intensity of attack. As many as 33 punctures were recorded on a *capsularis* plant in a pot culture. Lefroy [1907] records that in some cases one grub is found to almost every leaf.

TABLE V

Extent and itensity of Apion *infestation*

Number of punctures per plant	Frequency of infested plants (mean per cent)	
	Olitorius varieties C. G., R. 26 and Local	*Capsularis* varieties D. 154, D. 386 and Fanduk
0	38·58	16·63
1	25·09	16·29
2	19·22	17·19
3	10·74	19·80
4	4·37	14·82
5	1·37	7·92
6	0·25	3·72
7	0·12	2·04
8	0·12	0·68
9	0·00	0·57
10	0·00	0·23
11	0·00	0·00
12	0·00	0·00
13	0·00	0·00
14	0·00	0·11
15	0·00	0·11

Thirteen commercial samples obtained from the Director, Technological Research Laboratories, Calcutta, were examined for *Apion* damage. In each sample 'reeds' of 100 plants were examined. The percentage of damaged 'reeds' varied from 9 to 91 and the intensity of attack from 1·00 to 4·14 per attacked 'reed'. The amount of damage may best be expressed as an average number of *Apion* punctures per plant, irrespective of the plant being healthy or attacked.

TABLE VI

Damage in commercial fibre

Sample No. of T. R. L.	Attacked 'reeds' per cent (extent)	Average No. of knots in attacked 'reeds' (intensity)	Amount of damage (extent × intensity) 100
J. 93	9	1·11	0·10
J. 87	11	1·18	0·13
J. 97	13	1·00	0·13
J. 91	14	1·50	0·21
J. 86	36	1·77	0·64
J. 92	41	1·09	0·78
J. 94	50	1·64	0·84
J. 90	54	1·48	0·80
J. 89	60	1·51	0·91
J. 95	64	1·73	1·09
J. 96	65	1·94	1·26
J. 85	67	2·04	1·37
J. 88	91	4·14	3·77

With a view to note the amount of damage at different places, fibres obtained from quality trials were examined. From the results furnished in Table VII, it may be seen that in *capsularis* the Rangpur fibre recorded the maximum damage and the Faridpur one the least. The *olitorius* fibre from Berhampore, Chinsurah and Pabna recorded less knots than that of Dacca. *Apion* attack is wide-spread in Bengal and variation in damage from place to place is to be expected. Whether the incidence of *Apion* is less in pure *olitorious* tracts such as Chinsurah, Berhampore and Pabna is a point which requires further investigation and survey. Since the weevil prefers *capsularis*, it is to be expected that its incidence is more where only *capsularis* or both *capsularis* and *olitorius* are grown as at Dacca.

That the knots do not result from all the punctures is evident from the fact that the number of punctures observed in the standing crop is consistently higher than the number of knots in the corresponding fibre. It is, however, clear that a fair estimate of damage can be obtained even from the examination of fibre samples.

The crop around the borders is subject to heavier attack than the inner one. It may be seen from Table VIII that the percentage of infestation as well as its intensity are higher in the border crop.

TABLE VII

Amount of damage in quality trials, 1940

	Average No. of knots per 'reed'			Mean average knots in three varieties
	C. G.	R. 26.	Local	
Olitorius varieties	..	..	..	..
Pabna fibre .	0·20	0·27	0·19	0·22
Berhampore fibre	0·08	0·11	0·07	0·08
Chinsurah fibre .	0·13	0·11	0·12	0·12
Dacca fibre .	0·66	1·00	0·38	0·68
Standing crop, Dacca	1·09	1·45	1·19	1·24
Capsularis varieties	D 154	D 386	Fanduk	..
Rangpur fibre .	5·13	4·48	4·51	4·70
Faridpur fibre .	1·55	1·12	0·90	1·19
Dacca fibre .	1·53	1·77	1·59	1·63
Standing crop, Dacca	2·45	2·54	2·57	2·52

TABLE VIII

Direction of attack

	Capsularis border	*Capsularis* centre	*Olitorius* border	*Olitorius* centre
Per cent infested plants	97·77	86·95	73·22	59·71
Average number of punctures in infested plants	8·11	3·44	2·44	2·04
Average number of punctures in total plants	7·93	2·98	1·79	1·22

After the harvest of jute in low-lying areas such as *char* and *beel-lands*, the weevils fly to high-lands near the villages. They pass the winter in shrubs, weeds, bushes and hedges, and as soon as the new crop is available they come out and attack the nearest fields. Further away from the winter shelter, the attack, therefore, becomes gradually lighter.

Soil fertility. To find out the influence of fertilizers on *Apion* infestation, three years data from a manurial experiment conducted on the Dacca Farm were statistically analysed. It was found that the plots manured with super-phosphate in combination with calcium, or with ammonium sulphate in combination with super-phosphate and muriate of potash or potash alone suffered significantly less *Apion* infestation than the control farmyard manure plot. In general, nitrogenous manures increase *Apion* infestation, but potash and phosphatic fertilizers decrease it.

TABLE IX

Effect of fertilizers on Apion *infestation*

Treatments	Years			*Apion* infestation Average mean per cent
	1939	1940	1941	
fym	416·5	286·8	280·4	54·6
n	446·7	315·6	267·4	57·2
p	363·5	279·5	289·3	51·7
np	312·1	356·4	246·6	50·8
k	400·4	224·5	186·8	45·0
nk	343·6	377·7	307·7	57·1
pk	355·7	250·7	214·0	45·5
npk	311·5	246·7	205·5	42·4
ca	386·1	278·6	293·1	53·2
nca	445·2	299·8	304·8	58·3
p ca	324·5	234·7	170·3	40·5
np ca . . .	362·8	319·0	231·1	50·6
k ca . . .	427·7	208·1	267·8	50·2
nk ca . . .	273·9	265·5	274·7	45·2
pk ca . . .	367·8	259·5	208·1	46·4
npk ca . .	316·9	249·1	311·0	48·7
Critical difference	Insignificant	87·7	Insignificant	7·7

n = ammonium sulphate at 488 lb. per acre
o = super-phosphate at 314 lb. per acre
k = muriate of potash at 150 lb. per acre
ca = lime at 10 md. per acre
fym = farmyard manure (basal dressing for all treatments) at 100 md. per acre

Influence of date of sowing. Apion infestation of the top shoot is comparatively high in the early-sown crop than in the late-sown one, as from July onwards the weevils prefer laying eggs in the basa part of the stem. The late-sown crop is, therefore, attacked less at the top and more at the base. In a *capsularis* crop sown in the middle of July at two and half months ' age, tops and stem of only 5 per cent plants were infested, but the basal region of the stem of almost every plant was attacked, and immature stages were present therein.

Damage and disease. Apion punctures, particularly at the basal region, facilitate the entry of fungi like *Macrophomina Phaseoli* and *Sclerotium rolfsii*.

PARASITES

Though the pre-imaginal stages are passed inside the stem protected from the enemies, a high percentage of the grubs are subject to attack of two parasites. They await identification with the Imperial Entomologist, Imperial Agricultural Research Institute, New Delhi. One of the parasites belongs to the family *Miscogastridae* (*Chalcidoidea*) and could not be referred to any genus hitherto described. The other belongs to the family *Braconidae* (*Ichneumonoidea*).

The female of both the parasites is able to locate the grub that has not already been parasitized and paralyzes it by injecting poisonous fluid. The grub becomes inactive and the egg is deposited on its body. The parasitized grub from which a freshly laid egg or newly hatched larva (of parasite) has been removed does not remain alive for a long time. In no case more than one egg was found to have been deposited on the body of a single host. So far only one pupa parasitized by the *Chalcidoid* has been recorded. Soon after hatching, the braconid larva fixes itself to the body of the host for imbibing body fluid. The *Chalcidoid* larva enters the body of the host and feeds within. The full-fed larva pupates inside the stem.

The parasites are very useful in controlling the pest as they cause over 50 per cent mortality of the grubs (Table X). In the beginning of the jute season the parasitization is low, it reaches an optimum level in the mid-season, and declines towards the end.

TABLE X

Incidence of parasites

Months	Number of grubs examined	Per cent parasitized grubs	Collected from
1939 . .	190	62·6	Top and mid-stem
1940—			
June . .	447	36·9	Do.
July . .	419	57·5	Do.
August .	121	57·2	Do.
September .	469	55·1	Do.
Do. .	88	14·8	Stubble
October .	35	17·1	Do.
Do. .	32	9·4	Self-sown plant
1941—			
May . .	64	17·6	Top and mid-stem
June . .	157	28·7	Do.
July . .	142	57·0	Do.
August .	222	78·8	Do.
September .	20	85·0	Top of stem only
Do. .	135	35·8	Stubble
October .	184	37·0	Do.
Do. .	191	28·8	Basal part of stem
November .	539	48·9	Stubble
1942—			
May . .	113	29·2	Top and mid-stem
June . .	215	28·8	Do.
July . .	308	65·6	Do.
August .	206	84·5	Do.
September .	19	89·5	Top of stem only
Do. .	55	49·1	Stubble
Do. .	1948	64·4	Basal part of the stem
October .	2056	45·4	Do.
Do. .	148	62·8	Entire plant
Do. .	339	48·1	Stubble

CONTROL MEASURES

The insect completes its life-history in a protected state inside the stem and thus presents a most difficult problem. The adults are very small, and though found on the crop throughout the season, take very little food and as such cannot effectively be dealt with by any insecticide.

Lefroy [1907] states that unfortunately there does not appear to be any practical method of dealing with such a small insect, but suggests that it may be possible to get a trap crop for it. So far, no alternate host other than *bun-okra* (*Triumfetta rhomboidea*) has been found. As the weevil prefers to breed on jute, it is not possible to use *bun-okra* as a trap crop.

Over 50 per cent of the pest is destroyed by the two parasites. The importance of these parasites in checking the pest is very high. Pending the investigation of the question of utilizing the parasites for controlling the pest, the following control measures are suggested.

1. Destruction of immature stages by burning or retting of the infested plants during the early part of crop season, so that the activities of the pest can be checked right in the beginning. Infested plants can easily be located from their withered tops. The removal of infested plants during the early part of crop season will not affect the yield, as the crop has to be thinned subsequently. The plants removed during thinning should be collected and destroyed by submerging them in water.

2. Destruction of immature stages in the stubbles by collecting and burning or submerging stubbles immediately after the harvest of jute. The fields should be ploughed soon after harvest.

3. The self-sown plants which are found to be infested with the pest should be destroyed by ploughing or harrowing.

4. Destruction of immature stages by quick steeping of harvested jute. For easy handling and retting it is customary to stack the harvested jute for some time before it is steeped. For the first five days more parasites emerge from the cut jute than the weevils, but subsequently more weevils emerge than the parasites. It is, therefore, desirable not to stack the harvested jute for more than four days.

SUMMARY

Apion corchori Marshall, commonly known as the jute *Apion*, is a very important pest of jute affecting the quality of fibre. It is widely distributed in Bengal and other jute-growing provinces.

The eggs are laid singly in the stem near the base of the petiole, not very far from the apex. Occasionally the petiole and seed pods are selected for oviposition. During the late season oviposition is mostly confined to the basal part of the stem.

The maximum number of eggs laid by a female during an oviposition period of 124 days was 675. The highest number of eggs laid in a day was 13. The incubation period at room temperature is

3 days during summer and 5 days in January. The grub stage is extremely variable and occupied 8 to 18 days according to nutrition available in the stem. The pupal period is four days.

The maximum life of a weevil in captivity was 209 days. During the winter, a weevil lived for 35 days on water without any food.

Throughout the season, due to continuous multiplication by successive generations, the crop is heavily infested with all stages.

The adult causes very little damage. It is only the grub that is responsible for the damage which results in the formation of knot in the fibre deteriorating its quality.

Of the two cultivated species the *olitorius* is less susceptible. This might be due to higher tannin content in the latter's stem.

In gauging the damage, the percentage of infested plants as well as the intensity of infestation (number of punctures per plant) should be taken into consideration.

The crop around the borders is subject to heavier attack than the inner one. Away from the weevil's winter shelter the attack becomes gradually lighter.

The early-sown crop is attacked mostly at the top, and the late-sown at the base of the stem.

The plot manured with super-phosphates in combination with calcium or with ammonium sulphate in combination with super-phosphate and potash is less attacked by *Apion*.

In general, application of phosphatic and potassic fertilizer decreases *Apion* infestation, whereas the nitrogenous manures tend to aid its attack.

Two parasites are found to check the pest. They destroy over 50 per cent of the grubs.

The control measures suggested are based on the destruction of immature stages of the pest early and late in the season by destroying the infested material.

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EXPLANATION OF PLATE X

Fig. 1. Infested jute stem ; a—injury

Fig. 2. Split jute-stem showing the grub about to pupate ; b—grub

Fig. 3. Knotty fibre

Fig. 4. Transverse section of stem showing an egg ; a—epidermis ; b—cortex ; c—phlœm ; d—abnormal tissue growth (×40)

Fig. 5. Transverse section of stem at the place of injury ; a—epidermis ; e—tunnel ; f—deformed fibre bundles ; g—abnormal cortical cell-growth ; h—periderm (×8)

Fig. 6. Transverse section of stem showing tunnel made by the grub ; e—tunnel ; j—pupa (×12)

Fig. 7. Transverse section of knot ; a—epidermis ; f—fibre bundles ; g—abnormal cortical cells ; i—excreta (×12)

BIOLOGY AND CONTROL OF MAIZE AND *JOWAR* BORER (*CHILO ZONELLUS* SWIN.)

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Maize and *jowar* are amongst our most important grain crops. Though both are grown all over India, maize is more extensively cultivated in Bihar and North West Frontier Province, and *jowar* in Bombay, Central Provinces, Berar, Madras and Sind, while in the Punjab and the United Provinces they occupy extensive and almost equal acreage.

These crops are attacked by a number of insect pests of which maize and *jowar* borer (*Chilo zonellus* Swin.) is the most destructive, particularly in the Punjab where it has been under investigation for a number of years. This paper embodies the results of these investigations.

Life history*

Habits and response to light. Moths are nocturnal. During day they were found to rest on

*Most of the information given under this heading is taken from the annual reports of Bh. Amrik Singh (now working as Plant Protection Assistant at Hansi) who worked on this pest from February 1934 to October 1937 under the supervision and guidance of my predecessors, M. Afzal Husain and (the late) Dr R. L. Chopra, and myself

tree trunks, under clods and stones and among leaves. They are positively phototropic; during July-September their response to light was found to be at its height between 8 and 10 P.M.

Longevity of adults. The moths are short-lived; male and females observed from emergence to death lived respectively for 2-6 and 2-7 days in April; 1-4 and 2-6 days in May; 1-2 and 1-3 days in June; 1-3 and 1-3 days in July and August; and 1-2 and 1-2 days in September.

Number of eggs in a cluster and its size. Females lay oval, dull creamy eggs (which become black before hatching) in clusters on leaves. Each cluster contained 10-36, with an average of 23 eggs and measured from 3·1-12·0, with an average of 6·2 mm. in length and from 1·0-3·0, with an average of 20 mm. in breadth.

Progress of oviposition in the fields. The moths from the over-wintered larvae started oviposition in the fields in the last week of March, the subsequent generations of moths maintaining it right up to the end of October. Thus the egg clusters of *C. zonellus* were met with in the fields from the end of March to the end of October. These egg clusters were regularly collected from different fields in order to study the progress of oviposition. The results of these observations are given in Table I.

TABLE I

Progress of oviposition by Chilo zonellus *in the fields during March-October*

Month	Total number of plants examined in different fields	Number of egg-clusters found on these plants	Average number of eggs laid per month per 1000 plants
March (4th week)	1,000	3	3·0
April	6,000	149	24·8
May	10,500	30	2·8
June	9,500	22	2·3
July	17,000	118	6·9
August	14,100	256	18·1
September	25,300	77	3·8
October	22,500	46	2·04

It will be observed from the above table that the pest laid the largest number of eggs in April and August and fewest number of eggs in May, June and October.

Location of egg-clusters. According to Kuwayama [1928] *C. zonellus* lays its egg-clusters on the distal portion of a leaf. In the Punjab the position of 150 egg-clusters was studied on the leaves during April-June and it was found that of the total number of egg clusters laid on a leaf, 5·3 per cent of them were laid on the distal half, and the remaining 94·7 per cent within 2-5 cm. of the base of leaf.

Egg-stage. G. E. [1918], Ishikawa [1922] and Kuwana [1929] have found the egg-stage to occupy a week, 8-9 days and a week in Mesopotamia, Niigata and Japan respectively. In the Punjab duration of the egg-stage was studied for 4 years and it was found that the eggs laid in April hatched in 2 days while those laid during May-September and October took 3-4 and 5 days respectively to hatch (Table II).

Larval stage. G. E. [1918], Ishikawa [1922] and Kuwana [1929] have found the larval stage to occupy 30, 40-50 and 24-56 days in Mesopotamia, Niigata and Japan respectively during the active period. Duration of the larval stage of this pest was studied in the Punjab for 3 years and it was found that during the active period (i.e. April-September) it occupied 15-31 days (Table II).

Pupal stage. Kuwana [1929] has found the pupal stage to be completed in 7-8 days in Japan during the active period. With us in the Punjab the pupal stage had been found to occupy 2-9 days during April-September (Table II).

Duration of the pupal stage of the over-wintered larvae has been studied by Kuwana [1929] and Katsumata [1934] who found it to occupy 15 and 22·4 days respectively in Japan. In the Punjab pupal stage of the over-wintered larvae had been found to last for 8-15 days in March-April, and 7-8 days during May.

Duration of life-cycle. The pest completed its life-cycle in 24-39 days (Table II)

Number of generations. According to Kuwana [1929] *Chilo simplex* (*zonellus*) Butl. has two generations a year in Korea and most of Japan, one in the north and four in Formosa while according to Pang Hwa Tsai [1932] it has two, occasionally three, generations a year in China and according to Ishikawa [1922] it has two generations a year in Niigata. Number of generations of this pest was also studied in the Punjab. For this purpose it was reared continuously in muslin cloth sleeves on maize plants and it was found that it had 6-7 generations a year which overlapped each other.

Location of hibernating caterpillers. C. zonellus hibernates as a caterpillar from the 2nd week of October to the end of March. Observations made to study the location of hibernating caterpillars in the maize plant when the crop was being harvested during November-December. showed that 76·7 per cent of the caterpillars hibernated in stubbles, 13·5 per cent in stems and 9·8 per cent in cobs.

Almost all the caterpillars hibernating in stems and cobs are killed during winter as the former

TABLE II

Duration of life-cycle of C. zonellus

Eggs laid on	Eggs hatched on	Larvae pupated on	Adults emerged on	Duration of (in days)			Duration of life-cycle (in days)
				Egg stage	Larval stage	Pupal stage	
4 April . .	6 April . .	27 April—7 May .	6 May—13 May .	2	21—31	6—9	32—39
12 May . .	16 May . .	3 June—11 June	10 June—15 June	4	18—26	4—7	29—34
13 June . .	16 June . .	4 July—7 July .	11 July—14 July	3	18—21	7	21—31
13 July . .	17 July . .	1 August 13 – August	10 Aug.—18 Aug.	4	15—27	5—9	28—36
11 August .	15 August . .	2 September—12 September	8 September—14 September	4	18—28	2—6	28—34
12 September .	15 September .	30 September—5 October	6 October—13 October	3	15—20	6—8	24—31

are used as dry fodder for cattle and the grain from the latter as feed for man and livestock.

Similar observations were also made in connection with *jowar* and it was found that 12·2 per cent of the caterpillars hibernated in stubbles and 87·8 per cent in stems: in the stems they were mostly (79·0 per cent) found from 6-72 in. from the ground.

Emergence of moths from hibernating caterpillars. Emergence of moths from hibernating caterpillars was studied for three years. For this purpose a large number of caterpillars hibernating in stubbles and cobs of maize and *jowar* were kept in the laboratory. From stubbles, the emergence always started in the 1st week of April and was continued up to the 3rd week of June; 90·0 per cent of the moths emerging between the 2nd week of April and the 2nd week of May. From the cobs the emergence always started in the 3rd week of April and continued up to the end of June, 65·0 per cent of the moths emerging in May.

DAMAGE

C. zonellus does the most damage to grain rather than fodder crops of maize and *jowar*. It attacks all parts of the maize plant except roots; it bores in its stem and feeds on its leaves and cobs. In *jowar* it bores in the stem which is ridded with holes. Attacked plants often bend or twist over, and produce branches. Such plants remain stunted and die without producing grains. The attacked plants show 'dead-hearts', the bases of which smell offensively.

The caterpillars also bore into cobs and feed on ripening grains. 5445 cobs were examined at the time of harvest on 17, 27 and 29 November; 3, 8, 9, 11 and 12 December; and 20 January and the percentage of attack on them was found to vary from 2·6 to 24·3. Attacked cobs are further spoiled by the caterpillars voiding their whitish excreta on them.

RESISTANCE OF LOCAL AND FOREIGN VARIETIES OF MAIZE TO *C. Zonellus*

Punjab selected varieties. Experiments on the comparative varietal susceptibility of red Nos. 1, 2, 3, white No. 1 and local variety of maize to the maize and *jowar* borer were carried out and the percentage of attack on these varieties as recorded two months after sowing was found to be 20·1, 30·0, 20·7, 29·0 and 18·2 respectively.

U. S. A. varieties. Michigan corn hybrid 561 is claimed to be resistant to the European corn borer (*Pyrausta nubilalis* Hb.) in Michigan, U. S. A. To test its resistance to *C. zonellus*, 5 lb. of its seed was obtained through the courtesy of Mr A. R. Marston, Michigan State College of Agriculture and Applied Science, East Lansing, U. S. A., and sown at Lyallpur along with the local variety of maize. The percentage of attack was calculated about a month after sowing. The results of the two consecutive years (1939 and 1940) showed that Michigan corn hybrid 561 was as severely attacked and damaged by *C. zonellus* as the local variety of maize. Therefore, because of this fact and because of its poor yield and poor stand as compared to the local variety, Michigan corn hybrid 561 was discarded and the following other American corn hybrids (obtained through the courtesy of Mr Merle T. Jenkins, Principal Agronomist-in-Charge of Corn Investigations, United State Department of Agriculture, Bureau of Plant Industry, Washington) were tried at Lyallpur along with the local varieties during 1942. The results of these trials are given in Table III.

TABLE III

Resistance of American and local varieties to Chilo zonellus

(Date of sowing 10 August 1942)

Variety	Number of plants examined on 26 November 1942	Number of caterpillars found	Yield of grain per acre
			Md. sr. ch.
American—			
$B^2 \times$ Pr.	200	20	27 2 0
H1 × 960	200	5	38 2 0
$B^2 \times$ 38-II	200	9	39 35 0
$B^2 \times$ L317	200	13	11 0 0
$R^4 \times$ HY	200	8	13 3 0
$B^2 \times$ WF9	200	8	24 3 0
Local—			
Local (indigenous)	200	13	37 27 0
M. S. 28	200	16	33 19 0
U. S. 44	200	15	37 8 0
M. S. 63	200	10	27 13 0

The above table gives the results of the first year of the American varieties of corn under Punjab conditions. These trials are being continued and their results will be communicated in due course.

EFFECT OF STIMULATING PLANT GROWTH ON *C. Zonellus* INCIDENCE

When doing field work on *C. zonellus* it was noticed that when a maize plant was attacked before nodes were formed it showed a 'dead heart' and its growth was checked, but when it was attacked after node formation, it neither produced a 'dead heart' nor its growth was checked. It was, therefore, decided to study the effect of stimulating plant growth for earlier node formation by the application of nitrogenous manures on the incidence of pest. For this purpose experiments were laid out in 1940 and again in 1942. Since the results obtained in 1942 confirm the data obtained in 1940, findings of only 1942 are discussed.

In 1942 an area of 118 × 66 ft. was selected and divided into four blocks, each block being further sub-divided into four plots. The following four treatments with four replications of each were given by block randomization system: (1) Control, (2) Farm-yard-manure at the rate of 50 cart loads per acre, (3) Ammonium sulphate at the rate of 4 md. per acre added about a fortnight after sowing, (4) Farm-yard-manure and ammonium sulphate at the above rates. Maize was sown on 30 July. The plots were irrigated immediately after the addition of ammonium sulphate.

The damage was recorded in the first week of October. It varied from 16·0 to 18·25 per cent in the treated and control plots as is seen from Table IV: the results obtained were negative.

TABLE IV

Incidence of the pest in the control and treated plots

Treatment	Number of plants		Percentage of attack
	Examined	Attacked	
Control	400	71	17·7
Farm-yard-manure	400	73	18·25
Ammonium sulphate	455	72	16·0
Farm-yard-manure plus ammonium sulphate	400	71	17·7

MORTALITY AMONGST CATERPILLARS HIBERNATING IN MAIZE STUBBLES IN BERSEEM FIELDS

As pointed out above maize in the Punjab is generally followed by such fodder crops as 'senji' (*Melilotus parviflora*) or 'berseem' (*Trifolium-alexandrinum*) but 'berseem' is now more popular with the cultivators and is more extensively grown. Maize stubbles from 'berseem' fields were examined for hibernating borers. The results are presented in Table V.

TABLE V

Mortality percentage among caterpillars hibernating in maize stubbles in berseem fields

Month and week	No. of stubbles examined	No. of larvae found		Mortality percentage
		Living	Dead	
March				
I week	200	46	1	2·2
II week	300	63	2	3·0
III week	400	22	7	24·1
IV week	500	60	24	28·5
April				
I week	300	23	9	28·1
II week	300	28	17	37·7
III week	300	22	18	45·0
IV week	400	28	8	22·2
May				
I week	400	22	9	29·0
II week	200	9	5	35·7
III week	400	10	10	50·0

It will be observed from the above table that mortality amongst the caterpillars hibernating in maize stubbles in 'berseem' fields is quite appreciable and during 3rd week of March to 3rd week of May it ranged from 22·2 to 50·0 per cent.

THE EFFECT OF DATE OF SOWING ON THE INCIDENCE OF *C. Zonellus*

Experiments to study the comparative borer attack on maize sown on different dates were started in July 1935 and concluded in August 1942. These experiments were laid out at Montgomery, Lyallpur, Beas (Amritsar district) and Rawalpindi. Maize is an important crop and maize borer a serious pest in these localities. The experimental field selected for the purpose at all these places was divided into four blocks, each block being further sub-divided into four plots. Maize was sown four times during the season nearly after fortnightly intervals starting from mid-July and the sowings were done by block randomization system. Thus in all cases there were four sowings with four replications of each. The area of each experimental plot was 1/40th of an acre. Non-experimental strips were provided at each end of these plots.

In order to record the incidence of the pest, maize was examined 1-2 months after sowing. For this examination, three equal patches were selected at random from each plot and all the plants in them cut close to the ground and examined for caterpillars.

A large mass of experimental data have thus been collected and as all these data lead to, and confirm, the same conclusions only one year's results are given for each locality for the sake of brevity.

TABLE VI

Comparative C. zonellus *attack on maize sown on different dates*

Locality and year	Date of sowing	Date of examination	No. of plants		Percentage of attack	Population of borers per 100 plants
			Examined	Attacked		
Lyallpur, 1939	18 July	18 August	314	292	93·2	366·5
	31 July	30 August	331	224	67·6	132·1
	12 August	14 September	298	129	43·2	64·4
	24 August	25 September	304	39	12·8	34·8
Montgomery, 1939	15 July	14 September	1721	1256	73·0	106·5
	30 July	30 September	992	466	46·9	59·0
	15 August	15 October	1245	467	37·5	61·0
	30 August	30 October	1313	542	41·0	73·0
Beas, 1941	15 July	31 August	612	347	56·7	34·0
	31 July	16 September	583	200	34·7	27·4
	15 August	16 September	453	77	17·0	20·7
	1 September	16 October	565	52	9·2	8·1
Rawalpindi, 1942	22 July	15 September	571	97	17·0	80·4
	7 August	16 September	362	7	2·0	25·7
	22 August	31 October	651	45	7·5	35·5

It will be observed from the above table that the maize crop sown between 15 and 30 July suffered more from the pest than that sown between 7 August and 1 September.

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THE ONION THRIPS (*THRIPS TABACI* LIND.: THRIPIDAE: TEREBRANTIA: THYSANOPTERA)

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THRIPS tabaci Lind. is nearly a cosmopolitan pest which has been reçorded as occurring in such climatically different regions as South Europe, East and Central Europe, Asiatic Russia, India, Java, Japan, Australia, Hawaii, Chile, Mexico, U. S. A. and Canada. The presence of this pest in India was recorded for the first time by Karny in 1926 from the material collected by T. V. R. Ayyar as far back as March, 1920, from cotton flowers at Coimbatore while in the Punjab it was collected from Panipat, (District Karnal), in March, 1930, damaging onions and garlic. It was discovered at Lyallpur in 1935. Investigations on this pest were taken up seriously at Lyallpur in 1939 and this paper embodies the results of these investigations.

LIFE HISTORY

Thrips tabaci Lind. congregates in dense masses deep down in the narrow spaces between the axils of the inner leaves of the onion plant; it does not appear on the free portions of the leaves until present in very great numbers.

Oviposition. During March-June, two days after copulation, females started laying eggs. Eggs were laid singly in the leaf tissue on the underside of a leaf. A female laid 4-6 eggs per day and a total of 50-60 eggs in its life-time: according to MacGill [1927] a female laid 50-60 eggs in its life.

In leaves dehydrated in Alcohol and cleared in clove oil eggs could be seen as translucent spots under a binocular microscope.

The duration of the egg stage varied with the season: eggs laid in January-February hatched in 8-9 days while those laid in March, April, May and June took 7, 6, 5 and 4 days respectively to hatch. (For duration of egg stage in other countries see Table I below).

Nymphal instars. Eggs hatched out usually in the morning. The nymphal stage occupied 6 days during January-March and 4-5 days during April-June. (For duration of nymphal instars in other countries see Table I below.)

Pupation. Pupation took place in the soil throughout the year. The second instar nymph, when full fed, descended to the ground in which it burrowed to a depth of about an inch. Prepupal period occupied 1-2 days throughout the year while the pupal stage occupied 4 days during January-March, 3 days in April and 2 days in May-June.

Life-cycle. Table I gives the duration of the life-cycle of the pest in the Punjab and in other parts of the world.

TABLE I

Duration of life-cycle of T. tabaci *Lind. in the Punjab and other parts of the world*

Locality	Observer	Egg stage (days)	Larval stage (days)	Prepupal and pupal stages (days)	Total of immature stages (days)
Punjab	Rahman and Batra	4-9	4-6	3-5	12-19
Holland	Van Eecke	7	8	4	21-28
Massachusetts	Hind	4-7	7-8	7	21-28
Florida	Quaintance	3-4	7-9	4	16
Manchester	MacGill	8	10-14	5-9	23-31
Japan	Sakimura	3·6-6·3	6·4-14·0	4·5-10·3	14·5-30·3
U. S. A.	Eddy and Clarke	5	4-6	4·0-4·5	13·0-15·5

SEASONAL HISTORY AND FOOD-PLANTS

Seasonal history of *Thrips tabaci* Lind. was studied at Lyallpur during 1939-1941. The pest was found to appear on 'set onions', (grown from bulbs produced in the previous season) in the last week of November. It migrated from 'set onions' to 'seed onions' (grown from seed which are transplanted in January-February and harvested in June) in the beginning of spring when adults started laying eggs in large numbers. From about the beginning of March to the end of May all stages of the pest were found in the fields

and it was during this period that it did the greatest amount of damage to 'seed onions'. In June when the onions are harvested, the pest migrated to other food plants. Table II gives the food-plants of the pest monthwise.

TABLE II

Food-plants of T. tabaci *Lind. monthwise*

Month	Food-plant
October	1. Cabbage 2. Cauliflower
November December January February	3. 'Set onions' 4. Garlic
March April May June	5. 'Seed onions'
July August September	6. *Karela* (*Momordica charantia*) 7. Chillies 8. Lady finger 9. *Petha* (*Benincasa cerifera*) 10. *Halwa Kadu* (*Cucurbita maxima*) 11. *Tori* (*Luffa aegyptica*) 12. *Til* (*Sesamum indicum*) 13. Cotton 14. Brinjal

In other parts of the world this insect has been recorded as feeding, in addition to 1-5 above, on the following food plants by various investigators:

Parselay, cucumbers, melon, pumpkin, squash, turnip, tomato, lettuce, beets, beans, peas, celery, cotton, strawberry, blackberry, potato, sweet potato, lucerne, tobacco, spinach and wheat.

POPULATION SURVEY

A population survey of the pest on onions was carried out twice a week during November-May at Lyallpur and for this purpose 5 infested onion plants, which were selected at random from a field, were cut from the base with a sharp knife, enclosed in cellophane bags (measuring 12 in. × 6 in.) and brought to the laboratory, where they were carefully examined for nymphs and adults which were collected from them by unfolding the leaf blades one by one and afterwards counted under a binocular microscope. A record of rainfall as well as daily temperature was also kept. These data (lumped together from November to 3rd week of February and weekwise from 4th week of February to 2nd week of June) are presented in Table III.

TABTE III

Population of T. tabaci *Lind. on onions during November-June*

Month and week	Population per 5 plants	Temperature range in °F.	Rainfall in inches
November—3rd week of February	3-5	54·5-60·0	0·6
February IV	7	55·5-62·0	1·56
March I	12	57·0-64·5	0·66
II	26		
III	68		
IV	79		
April I	161	71·0-80·5	...
II	175		
III	220		
IV	180		
May I	126	86·0-92·0	...
II	82		
III	20		
IV	3		
June I	...	96·0	...
II	...		

PARTHENOGENESIS

Parthenogenesis is a common phenomenon among thrips and is also met with in *T. tabaci*, the parthenogenetically produced progeny consisting of females only. During March-June, 1940, 400 adults were examined and all of them were found to be females: Sakimura [1937] collected 5019 adults throughout the year in the vicinity of Tokyo from onions and found them all to be females.

DAMAGE

The injury which onion-thrips inflicts on the onion plant is called 'white blast', 'white blight' or 'silver tops', the whitened appearance of the onion leaves being due to the extraction from them of plant juices, first by rasping and then by sucking both by the adults and the nymphs. The attacked leaves become curled, crinkled and even twisted. The pest was found to do the greatest damage during dry seasons when it destroyed 75 per cent of the crop.

CONTROL

a. Sprays

Following insecticides, prepared according to the formula given against each, were tried against the pest during 1939 and 1940.

Tobacco decoction—

Tobacco refuse	1 lb.
Cheap soap	4 oz.
Water	1 gallon

Ak decoction

Ak (*Calotropis procera*)	2 lb.
Cheap soap	8 oz.
Water	3 gallons

Nim (*Melia azadirachta*) and *dhatura* (*Datura spc.*) decoctions prepared according to the above formula were also tested.

Rosin solignum soap

Rosin solignum soap	12 oz.
Water	4 gallons

Black leaf 40—

Black leaf 40	1 oz.
Fish oil soap	8 oz.
Water	6 gallons

Derrisol (Liquid katakilla)—

Derrisol	1 oz.
Fish oil soap	8 oz.
Water	5 gallons

Results are given in Table IV.

TABLE IV

Efficacy of different insecticides against T. tabaci

Serial number	Insecticide	Mortality percentage	Cost per acre
1	Tobacco decoction .	75	Rs. 2
2	*Ak* decoction . .	61	Re. 1
3	*Nim* decoction .	57	Re. 1
4	*Dhatura* decoction .	52	Re. 1
5	Rosin solignum soap	66	Re. 1—12
6	Black leaf 40 . .	82	Rs. 6
7	Derrisol . .	75	Rs. 8

It will be observed from the above table that Black leaf 40 gave a mortality of 82 per cent at a cost of Rs. 6 per acre.

It may be pointed out that a field of healthy onions is sold at Rs. 180-200 per acre but when infested with the onion thrips it may be sold for anything up to Rs. 25 per acre.

b. Dusts

Various dusts such as Nicotine dust (3 per cent), Tobacco dust (50 per cent), Naphthaline dust (33 per cent) and Crude Naphthaline were also tried against *T. tabaci*. These gave a mortality percentage of 26·8, 32·9, 14·1 and 18·5 at a cost of Rs. 8-8, Rs. 6-6, Rs. 2-8, and Rs. 16 per acre, respectively.

Maughan [1932] tried various dusts and sprays for the control of onion thrips (*Thrips tabaci* Lind.) on onions in Ithaca (New York) and found Nicotine preparations to be most effective in general, with kerosene, pyrethrum products, naphthaline and copper sprays or dusts giving high degrees of control.

SUMMARY

Thrips tabaci Lind. is a cosmopolitan insect which has been recorded as feeding on a large number of food plants. It is, however, a serious pest of onions.

In the Punjab, it completes its life-cycle in 12-19 days during the active period—January to June—as follows:

Egg stage, 4-9; larval stage, 4-6; prepupal and pupal stages, 3-5. Prepupal and pupal stages are passed in the soil at a depth of 1-2 in.

Onion thrips appears on 'set onions' in November and remains on them till February: during this period it does little damage. It becomes active in March and its damage is at its highest during March-May. During June, it migrates to Malvaceous and Cucurbitaceous plants.

Parthenogenesis is a common phenomenon among these thrips, the parthenogenetically laid eggs producing females only.

The pest can be effectively controlled by spraying with Black leaf 40.

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VARIATION IN THE MEASUREABLE CHARACTERS OF COTTON FIBRES

VIII. VARIATION BETWEEN REGIONS OF THE SEED SURFACE

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Koshal and Ahmad [1932] have made detailed study on this point and find considerable differences among the different regions. Recently Moore [1941] also has observed similar variation. In Koshal and Ahmad's work the fibres on the whole seed were divided into four regions and examined. Besides, the seeds were obtained from the bulk sample. It was, therefore, thought interesting to study whether the variation observed would be reduced if a more uniform sample was chosen and if the fibres were taken from over a smaller region of the seed surface. This study is dealt with in the following pages.

Material and sampling

Four four-locked bolls picked from a single plant of Co. 2 on 14 March 1931 supplied the material for this enquiry. Out of this produce all the nine-seeded locks, with no undeveloped bolls, were separated. The seeds in the lock were numbered in the manner described elsewhere [Iyengar, 1941, 1] and sorted out according to the position of the seed in the lock. Thus nine main samples were obtained.

The surface of the seed was divided into six regions, namely (1) micropylar end (2) region close to the raphe (3) right side of the raphe (4) left side of the raphe (5) back of the raphe and (6) the chalazal end. The full halo was combed, care being taken to have as small a combed waste as possible. By means of dissecting needles fibres situated over the exact regions were separated and pulled out by hand. In order to avoid overlapping, bunches of fibres arising on the borderland between two contiguous regions were rejected. The fibres of the corresponding regions were put together and these formed the samples for examination. In some of the samples the raphe and back regions were not examined.

Experimental

The whole sample was made into a sliver and the mean fibre length was determined by means of the Balls sorter. As the sample was small only one Balls sorter test was made. The fibre weight per cm. was then determined by weighing 2,000 fibres cut to cm. lengths. (The cutting method was employed as the whole fibre-weighing-method was not in vogue when this work was done). The remaining portion of the sliver was used to determine the maturity percentage by using Clegg's [1932] method. Ten tufts of about 100 fibres each were examined for each sample.

Results

(a) Variability of length

Before taking up the mean length for each region the variability of the length in each region may be considered. In the present study this is assessed by the coefficient of variation of the length distribution as obtained by the Balls sorter.

The values of coefficient of variation given in Table I are the mean values. The individual values were found to vary from 14·0 to 25·1 per cent. The variation of the coefficient is considerable at the micropylar end. The mean value for this region is higher than for the others. The cause of the higher variability shown by the micropylar region may be the following. The mean fibre length for this region will be seen later to be considerably smaller than that for the other regions. If, therefore, instead of taking the fibres exactly over the micropylar end, it is taken over a slightly wider region a number of longer fibres enter into the sample and thus increase the variability. This effect is not prominent in the other regions as no such sharp variation in length occurs there.

The results considered above are for the different positions of the seed in the lock of one cotton, Co. 2. The coefficient of variation calculated from figures given by Koshal and Ahmad [1932] for four regions for eight cottons also indicate the same fact.

(b) Fibre length

The mean value for the micropylar region, 0·88 in., is significantly less than for the others. The right side and the left side having respectively mean lengths of 0·97 in. and 0·98 in. do not differ from each other. The mean length of

TABLE I

Fibre properties in the different regions of the seed

Property	No. of tests	Micropylar region	Chalazal region	Right side	Left side	Raphe* region	Back* region	Critical difference $P=0·05$
1. Coefficient of variation of length per cent	9	20·5	18·6	16·3	15·7	19·0	15·1	...
2. Mean length (in.)	9	0·88	1·00	0·97	0·98	0·91	0·95	0·023**
3 Mean fibre wt. per cm. (10^{-6} gm.)	9	2·88	1·44	2·25	2·23	2·29	2·25	0·138**
4. ‡Mature fibres per cent.	9	88·0	30·1	76·6	72·1	86·0	69·0	... **
5. ‡Immature fibres per cent.	9	6·2	56·3	13·0	14·9	8·0	15·0	... **
6. Standard fibre wt. (10-6 gm.)	9	2·68	1·93	2·21	2·23	2·26	2·26	0·172**
7. Fibre cell diameter 2 days old (microns)	6	15·4±0·26	12·4±0·16	13·7±0·21	... ...	... ...	...	... ...
8. Fuzz diameter (microns)	4	30·3±0·81	25·3±0·68	25·6±0·72	... ...	... ...	...	... ...
9. Fibre diameter (microns)	3	25·6±0·43	21·2±0·34	22·1±0·27	... ...	... ...	...	... ...
10. Strength of attachment of the fibre to the seed (gm.) Co. 2	2	3·20±0·22	1·32±0·10	2·78±0·18	2·28±0·16	2·50±0·23	2·40±0·15	... ...
K. C. 7	1	4·28±0·37	1·37±0·22	2·54±0·19	2·48±0·18	2·97±0·23	2·54±0·17	... ...

* The number of tests for properties 1 to 6 is only three for these two regions and the analysis of variance has not been applied to these regions

‡ For these properties the analysis of variance has been done using the inverse sine transformation

the chalazal region, 1·00 in., appears to be significantly higher than that for the right side and is nearly so than that for the left side. The mean for the raphe region, 0·91 in., indicates a smaller value but as it is based on three values only requires further confirmation. The mean length for the back region, 0·95 in., which is also derived from three values only, may not be significantly different from the right and left sides.

In another study [Iyengar, 1941, 2], only two regions, micropylar and chalazal, were studied for the same cotton, Co. 2. It is found that on the average the length is 0·88 in. for the micropylar and 1·00 in. for the chalazal end, coinciding with the mean values obtained above. The coincidence is, however, due to chance but it can be taken as an indication of good agreement.

The foregoing conclusions are in conformity with those drawn by Koshal and Ahmad [1932] and Moore [1941].

(c) *Fibre weight per cm.*

The mean value, 1·44, for the chalazal end is considerably less than that for the other regions. Similarly that for the micropylar end, 2·88, is significantly higher. The mean values for the other regions which vary from 2·23 to 2·29 do not indicate significant variation.

In the other study [Iyengar, 1941, 2], the mean fibre-weight for the micropylar end was got to be 2·86 and for the chalazal end 1·26, which are in substantial agreement with the present findings.

These results, like the length results, are in agreement with those of Koshal and Ahmad [1932] and of Moore [1941]. In some of the cottons studied by Koshal and Ahmad, however, the reduction in the fibre weight at the chalazal end is not as large as that found in the present work.

(d) *Fibre maturity*

Taking the mature fibres first it will be seen that the mean for the chalazal region, 30·1 per cent is very much smaller than that for the others. The mean for the micropylar end, 88·0, is higher than that for the right (76·6) or left (72·1) sides. No definite conclusion can be drawn regarding the raphe and back regions, as the mean values are based on three positions only. The immature fibres also confirm the previous statements. The chalazal region with 56·3 is considerably more immature and the micropylar region with 6·2 less immature than the other regions.

The results obtained for 14 strains in another study [Iyengar, 1941, 2] point to the same conclusion. In some of the strains, however, the variation in the different regions is not so considerable as observed in the present case. Moore [1941] and also Campbell, quoted by him, have also observed the same kind of variation.

Moore [1941], however, has attempted to correlate the variation in the fibre weight and

TABLE II

Number of fibres and nutrition supplied to the chalazal and micropylar regions

(Calculated from the figures given by Moore)

No.	Cotton	Number of fibres in 3·567 sq. mm.			Nutrition gm./cm²			B/A
		Ch.	Mic.	Ch./Mic. A	Ch.	Mic.	Ch./Mic. B	
1	Mexican 128 . .	1,457	317	4.6	16.7	5.5	3·0	0·65
2	Coker Cleveland 884-4 .	2,044	241	8·5	19·1	4·1	4·7	0·55
3	Farm Relief No. 1 .	1,493	256	5·8	16·1	4·7	3·5	0·60
4	Acala 4067 . . .	1,646	406	4·1	15·7	6·2	2·7	0·66
5	Rowden 40 . . .	1,725	216	8·0	19·3	3·7	5·2	0·65
	Mean .	1,673	287	5·8	17·4	4·9	3·5	0·60

maturity in the different regions with the number of fibres produced per unit area of the region. For the sake of simplicity two regions (1) and (6) of his study, which correspond to the chalazal end and the region close to the micropylar end may be considered here. The number of fibres produced in the punched area is given by him. The quantity of nutrition supplied can be got by multiplying the number of fibres by the corresponding mean length of the fibres and the fibre weight per unit length. The values thus obtained are given in Table II. They indicate that the number of fibres produced at the chalazal end is relatively very much greater—4·1 to 8·5 times the number near the micropylar region. The quantity of nutrition supplied is also considerably higher in the former region but not as great as observed in the number of fibres, being only 2·7 to 5·2 times. Thus each fibre at the chalazal end receives relatively less nutrition than at the micropylar end, being on the average about three-fifths. This accounts for the lower fibre weight per unit length and lesser degree of maturity shown by the fibres produced in the former region. The cause of the reduced nutrition appears to be, as shown by Moore, the relatively large amount of intermicellar space between the vein and the epidermal layer at the chalazal region.

(e) *Standard fibre weight*

The mean value for the micropylar region, 2·68, is significantly more than that for the other regions. Similarly, the value for the chalazal end, 1·93, is significantly less. The variation among the other regions, 2·21 to 2·26, is not significant. The increase at the micropylar end over that at the chalazal end is 39 per cent of the latter value. The increase in the case of the actual fibre weight per cm. is found to be 100 per cent. In the other study [Iyengar, 1941, 2] the corresponding increases were found to be 44 and 127 per cent respectively. It means that the variation in the maturity or in the secondary thickening accounts for about two-thirds of the variation observed in the fibre weight, the remainder being due to the differences in the diameter of the fibre cell. From the above it follows that this diameter is largest at the micropylar end, smaller at the sides and still smaller at the chalazal end.

The results obtained for the actual uncollapsed diameter in another study [Iyengar, 1943] confirm the above findings. This feature appears to be true even in ovules which are very young. The diameter of the sprouting cell was determined for ovules of Co. 2, two days old, grown at Coimbatore. Three regions, micropylar end, right side and chalazal region have been studied in each case. At exactly the micropylar end no fibres are formed at the age of two days. Hence the diameter of the fibres nearest that region was determined. Six ovules have been studied and the results show that in each case the diameter for the micropylar region (15·4) is greater than that for the right side (13·7) which in turn is greater than that for the chalazal end (12·4), just as is found in mature seeds.

The diameter of the fuzz fibres also signifies a similar tendency. The fuzz was swollen in 18 per cent caustic soda and about 100 to 170 fibres were measured for each region of a seed. Four seeds of Co. 2 (fifth seed of nine-seeded locks) were examined. The results denote that in all cases the micropylar region (30·3) indicates a significantly higher value as was found in the

case of lint fibres. But the difference between the chalazal region (25·3) and the right side (25·6) is not significant.

The diameter of fuzz is greater than that of lint in all cases agreeing with the finding of Balls [1928] and of Brown [1938]. But the other statement of Brown that as the cell wall is thin, they resemble immature or undeveloped fibres is not borne out. The results obtained for Co. 2 cotton show that the maturity of the fuzz from all over the seed is 95—3. Even at the chalazal end, where the lint fibres were found to be very immature, the maturity of the fuzz is 84—12, while for lint from the same seeds it is 42—46. In another sample the maturity of fuzz at the chalazal end was found to be 94—4 as against the maturity of lint of 57—29. It is thus seen that the fuzz fibres are considerably mature agreeing with the statement of Balls [1928] that these fibres show restricted length-growth with rank thickness-growth.

(f) *Strength of attachment of the fibre to the seed*

This is a new property studied in this connection. It was measured by finding the force required to pull out the fibre by loading it by means of the O'Neill float. The seed was held in a padded clamp and the other end of the fibre to which an eyelet was fixed supported the float. Thirty fibres were pulled out for each region of the seed. The six regions described above have been studied in this case also. For this work a small tuft sprouting exactly on the required region was separated by means of a needle. Fibres from this region were mounted one after another and pulled out and the weight required for the pull was determined.

Two seeds of Co. 2 and one of Karunganni C. 7 have been examined. Unfortunately the work could not be extended to more samples on account of various causes. The results obtained indicate that the strength of attachment of the fibre to the seed is greatest at the micropylar end, least at the chalazal end and intermediate in the other regions, the differences among which are not conspicuous. The low strength at the chalazal end may be due to the fact revealed in Plate 2 of Moore's [1941] work. The structure of the cells at the chalazal end is not quite uniform and there is considerable intermicellar space, while in the other region the structure is more uniform with a relatively small amount of intermicellar space.

Discussion

Summing up the foregoing it may be stated that (1) at the micropylar region the fibres are thinly populated, short, very mature, have the highest fibre weight, standard fibre weight, fibre diameter, fuzz diameter and fibre strength and are most firmly attached to the seed; (2) at the chalazal end the fibres are very densely populated, are longer and more immature—considerably more immature in some cottons—have smaller fibre weight per cm., standard fibre weight, fibre diameter and fibre strength and are less firmly attached to the seed; and (3) at the other regions the variations among themselves do not appear to be conspicuous; generally speaking the values lie intermediate between those for the two regions considered above, though they approach the values for either of the two regions in some cases.

The probable cause for the variation observed in the different regions may now be considered. On this point Balls [1928] says 'No doubt it is largely a question of nutrition, dependent upon the anatomy of the vascular bundles on the seed-coat.' Talking about the cross-sectional area of the fibre he states that 'The proximate causes for this variation can be traced to the life history of the hair. It depends only slightly upon the variations in the original diameter of the cell. Principally it is brought about by the differences in the thickening of the secondary wall.' The present results in the case of the micropylar and chalazal ends of the seed indicate that about two-thirds of the weight is accounted for by secondary thickening, the rest one-third being due to the original cell diameter. Moore's [1941] findings of the venations on the seed-coat and of the differences in the structure of the cells below the epidermis in the different regions offer a partial explanation. Further critical enquiry is indicated.

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STATISTICAL NOTES FOR AGRICULTURAL WORKERS

No. 27. CALCULATION OF STANDARD ERRORS AND TESTS OF SIGNIFICANCE OF DIFFERENT TYPES OF TREATMENT COMPARISONS IN SPLIT-PLOT AND STRIP ARRANGEMENTS OF FIELD EXPERIMENTS

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(With two text-figures)

In agricultural field experiments conducted to study simultaneously the effects of variation of more than one factor, research workers find practical difficulties in completely randomizing all the treatments within a single block. To remedy this operational difficulty two designs called Split-Plot and Strip Arrangements have been devised which have become quite popular among agricultural workers. But from the statistical point of view of precision of treatment comparisons these designs suffer from certain drawbacks. Thus, the more important comparisons called main effects are less precisely estimated than interactions.

Tests of significance of comparisons which involve only one of the main effects or of the interactions are quite straightforward and reduce to t-test. But sometimes even in factorial experiments one may like to compare any two treatment combinations and the calculation of their standard errors is a little complicated and the method is not widely known. As a result many are not aware of the fact that the test of significance of these comparisons cannot be made by Student's t-test. It will be shown in the note that the Behrens and Fisher's test for which Sukhatme [1938] has published convenient tables can be applied for certain comparisons and that there are also comparisons for which no exact test of significance is known.

Strip arrangement

Let us consider a two factor experiment with p variants, $a_1, a_2, \cdots a_p$ of a factor A and q variants $b_1, b_2, \ldots b_q$ of a factor B in all combinations each replicated in r blocks. Each block is divided into p column strips to which $a_1 \cdots a_p$ are assigned at random; and divided into q row strips to which $b_1 \ldots b_q$ are assigned at random. Such a lay-out is called a Strip Arrangement. Fig. 1 represents a typical block. It will be noted that there is no free randomization for each treatment combination $a_i\, b_j$ within the block.

The structure of the analysis of variance of plot yields is shown in Table I.

The standard errors σ_0, σ_1, σ_2, σ_3 are those associated with plots of the size and shape represented in Fig. 1 by AEKD, ABCD, AEFG and ABHG respectively. If the yields of all the pq plots of size A B H G were all uncorrelated, it is easy to show that $\sigma_0=\sigma_1=\sigma_2=\sigma_3$. In other words the standard errors associated with different plot sizes when they are all reduced to the same scale can be the same in only 'random' fields. It is a very widely verified fact that adjacent plots of a field are highly and positively correlated owing to certain regularity in fertility variation.

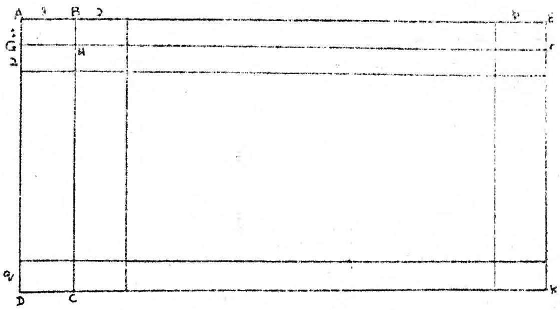

Fig. 1. One block of a strip arrangement

Table I

Analysis of Strip Arrangements

	D. F.	Variance	
		Observed	Expressed under nullhypothesis
Blocks	$r-1$	V_0	σ_0^2
Main effect: A	$p-1$	V_a	σ_1^2
Error (1)	$(p-1)(r-1)$	V_1	σ_1^2
Main effect: B	$q-1$	V_b	σ_2^2
Error (2)	$(q-1)(r-1)$	V_2	σ_2^2
Interaction: A × B	$(p-1)(q-1)$	V_{ab}	σ_3^2
Error (3)	$(p-1)(q-1)(r-1)$	V_3	σ_3^2
Total	$pqr-1$		

Based on this phenomenon it is possible also to build up an abstract theory about the quantitative behaviour of these correlations as has been put forward by Mahalanobis [1942], who uses the term 'correlation function' to describe this relationship. In his theory, all pairs of plots at an equal distance may be assumed to give one value for the correlation, whatever be the direction of the line joining the centres of the two plots. By exhausting all pairs of plots situated at distance d_1, d_2, ... d_n we can get n values of correlation, r_1, r_2, ... r_n. Plotting d and r along x and y axes we get a graph of the correlation function which may then be suitably graduated. The general shape of the correlation function with which we come across in agricultural field experiments is shown in Fig. 2.

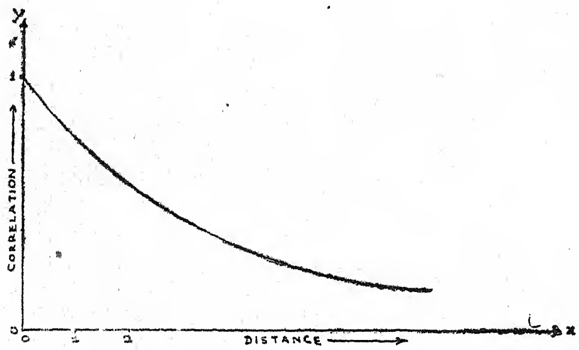

FIG. 2. Correlation function for agricultural fields

The correlation is obviously + 1 at distance 0 but decreases to 0 as distance between pairs of plots increases indefinitely. The correlation never becomes negative if sufficient pairs of plots are included.

Having accepted the above form of the correlation function, it simply follows that σ_1 and σ_2 must be less than σ_0 and greater than σ_3. The difference between σ_1 and σ_2 will mostly depend on difference in area between plots ABCD and AEFG, that is, on the difference between p and q, but will also be controlled by the 'differential' shape of these plots which also depends on p and q. They will be very dissimilar in shape if the plot ABHG gets narrower in shape. If $p = q$, the shapes will be the most important factor influencing the relative magnitude of σ_1 and σ_2. It follows from the form of the correlation function shown in Fig. 2 that narrow plots are less variable among themselves than square ones of the same area. This is for the obvious reason that in the former plots there are proportionately more pairs of distant components [or *quads* as Mahalanobis (1942) calls them] with small correlations than in the latter plots. Thus, in our case, σ_1 will be greater than σ_2 when $p=q$, if AB is greate than AG and *vice versa*.

Whatever be the relative magnitudes of σ_1, σ_2 and σ_3, it is enough to note that they are not likely to be equal. We have to make separate estimates of them, namely, the square roots of V_1, V_2, V_3 of Table I. The observed variances Va, Vb and Vab for main effects of A of B and of interaction A × B respectively should be tested against V_1, V_2, V_3 by the 'Ratio of Variance' test.

Besides the above analysis of variance it is necessary to make detailed comparisons between pairs of treatment combinations of which there are three main types namely:

(*i*) Comparison between variants of B for a given variant of A, Ex. $a_1 b_1—a_1 b_2$.

(*ii*) Comparison between variants of A for a given variant of B, Ex. $a_1 b_1—a_2 b_1$.

(*iii*) Comparison not included in (*i*) and (*ii*), Ex. $a_1 b_1—a_2 b_2$.

These comparisons can be expressed in terms of the two main effect comparisons of the type $\left(\sum\limits_1^q b_i\right)(a_1—a_2)$ and $\left(\sum\limits_1^p b_i\right)(b_1\text{-}b_2)$ and interaction comparisons of the type $(a_1\text{-}a_2)$ $(b_1\text{-}b_2)$ which are mutually orthogonal and whose standard errors depend on σ_1, σ_2 and σ_3 respectively. To calculate the variance of $a_1b_1\text{-}a_1b_2$ which may be denoted by $V(a_1b_1—a_1b_2)$, we must proceed as follows:

$$p\,(a_1 b_1— a_1b_2) = \left(\sum_1^p a_i\right)(b_1\text{-}b_2) + \;[(a_1\text{-}a_2) + ..$$
$$+(a_1—a_p)]\,(b_1\text{-}b_2) \qquad .. \quad .. \quad .. \quad .. \quad (1)$$

It may thus be noted that $a_1b_1—a_1b_2$ splits into two component parts, one involving main effect of B and the other the interaction A × B. The two parts are obviously orthogonal and therefore

$$p^2V\,(a_1 b_1—a_1 b_2)=V[\,(\Sigma a_i\,)\,(b_1—b_2)]+$$
$$V\left[\left\{(p—1)\,a_1—a_2—\ldots—a_p\right\}(b_1—b_2)\right] \;.. \quad (2)$$

If the comparisons are estimated on a per plot basis from r replications

$$p^2\,V\,(a_1\,b_2 — a_1\,b_2) = \frac{2\,p}{r}\,\sigma_2{}^2 + \frac{2p(p—1)}{r}\;\sigma_3{}^2$$

$$or\;V\,(a_1\,b_1—a_1\,b_2) = \frac{2}{r}\left(\frac{\sigma_2{}^2 + (p—1)\sigma_3{}^2}{p}\right) \;.. \quad (3)$$

Similarly, to calculate the variance of $a_1\,b_1—a_2b_1$, we have $q\,(a_1\,b_1—a_2\,b_1) = \left(\sum\limits_1^q b_i\right)(a_1—a_2) + [(b_1—b_2)+..+(b_1—b_q)\,]\,(a_1—a_2)$ .. .. .. (4)

$$\text{and } q^2\,V\,(a_1\,b_1—a_2\,b_1) = \frac{2q}{r}\,\sigma_1{}^2 + \frac{2q\,(q—1)}{r}\,\sigma_3{}^2$$

$$or\ V(a_1 b_1 - a_2 b_1) = \frac{2}{r}\left(\frac{\sigma_1^2 + (q-1)\sigma_3^2}{q}\right) \quad .. \quad (5)$$

Coming now to the third type of comparison, namely, $a_1 b_1 - a_2 b_2$, we have

$$2(a_1 b_1 - a_2 b_2) = (a_1 + a_2)(b_1 - b_2) + (a_1 - a_2)(b_1 + b_2) \quad .. \quad (6)$$

$$\text{and } 4V(a_1 b_1 - a_2 b_2) = V[(a_1+a_2)(b_1-b_2)] + V[(a_1-a_2)(b_1+b_2)] \quad .. \quad (7)$$

To calculate each of the variances on the r. h. s. of (7) :—

$$p(a_1+a_2)(b_1-b_2) = 2\left(\sum_1^p a_i\right)(b_1-b_2) + [(p-2)(a_1+a_2) - 2\sum_3^p a_i](b_1-b_2) \quad .. \quad (8)$$

$$p^2 V[(a_1+a_2)(b_1-b_2)] = \frac{8p}{r}\sigma_2^2 + \frac{4p(p-2)}{r}\sigma_3^2$$

$$or\ V[(a_1+a_2)(b_1-b_2)] = \frac{4}{r}\left(\frac{2\sigma_2^2 + (p-2)\sigma_3^2}{p}\right) \quad .. \quad (9)$$

Similarly

$$V[(a_1-a_2)(b_1+b_2)] \frac{4}{r}\left(\frac{2\sigma_1^2 + (q-2)\sigma_3^2}{q}\right) \quad .. \quad (10)$$

In general

$$V[(a + a_2 + .. + a_k)(b_1 - b_2)] = \frac{2k}{r}\frac{k\sigma_2^2 + (p-k)\sigma_3^2}{p}) \quad .. \quad (11)$$

$$V[(b_1 + b_2 + ... + b_k)(a_1 - a_2)] = \frac{2k}{r}\left(\frac{k\sigma_1^2 + (q-k)\sigma_3^2}{q}\right) \quad .. \quad (12)$$

When k equals p and q respectively, σ_3 drops out from (11) and (12) as it should be.

Adding (9) and (10) we have

$$V(a_1 b_1 - a_2 b_2) = \frac{2}{pqr}\left(p\sigma_1^2 + q\sigma_2^2 + (pq-p-q)\sigma_3^2\right) \quad .. \quad (13)$$

Tests of Significance. Both $a_1 b_1 - a_1 b_2$ and $a_1 b_1 - a_2 b_1$ are quantities whose standard errors are measured by estimates of two unequal variances and hence not capable of being tested by Student's t.

Similarly comparisons whose variances are given by (11) and (12) cannot also be tested by Student's t unless $k=p$ in (11) and $k=q$ in (12) in which case they reduce to main effect comparisons. For other values of k we can apply the Behrens and Fisher test which Sukhatme [1938] calls d-test. Thus taking (11), we have

$$d = \frac{(a_1 + a_2 + \dots + a \quad (b_1 - b_2)}{\sqrt{\frac{2}{r}\left\{kV_2 + (p-k)V_3\right\}}} \quad (1 \leqslant k < p) \quad (14)$$

and we have to enter Sukhatme's tables with $n_1 = (q-1)(r-1)$, $n_2 = (p-1)(q-1)(r-1)$ and θ given by $\tan\theta = \sqrt{kV_2/(p-k)V_3}$.

Similarly for (12)

$$d = \frac{(b_1 + b_2 + \dots + b_k)(a_1 - a_2)}{\sqrt{\frac{2k}{rq}\left\{kV_1 + (q-k)V_3\right\}}} \quad (1 \leqslant k < q) \quad (15)$$

with $n_1 = (p-1)(r-1)$, $n_2 = (p-1)(q-1)(r-1)$ and $\tan\theta = \sqrt{kV_1/(q-k)V_3}$.

The assumption in the d-test is that neither the two population variances nor their ratio are known, but in our experiment we have an almost certain knowledge which of the two variances is greater so that we can set the boundary for the ratio of variance as always lying above 1. But this information is not being utilized by the d-test. Yates [1939] has made a careful study of the d-test from which it appears that by not taking into account the *a priori* knowledge of the range of values of the unknown ratio of variances, the proportion of samples judged significant will be less than the actual level of significance adopted would indicate.

Coming now to the last type of comparison namely, $a_1 b_1 - a_2 b_2$, its standard error involves three unequal standard deviations σ_1, σ_2 and σ_3. Neither the t nor the d test is applicable to it. Since $(a_1 + a_2)(b_1 - b_2)$ and $(a_1 - a_2)(b_1 + b_2)$ have to be tested by d, we can look at $a_1 b_1 - a_2 b_2$ as a compound of two d values, just in the same way as d is a compound of two t values, but there is no known method of testing its significance.

SPLIT-PLOT ARRANGEMENT

If we had split-plot design instead of the above strip arrangement, σ_2 and σ_3 will stand for the same standard deviation if the variants of factor A occupy the main plots ABCD, etc., and the q variants of B are perfectly randomized among q sub-plots, ABHG, etc. of each main plot. The effect of any particular variant of B will no longer be estimated from compact strips of the type AEFG. The new σ_2 which measures the uncontrolled fertility variation between plots of the type ABHG within main plots of the type ABCD, can be estimated with $p(q-1)(r-1)$ degrees of freedom by pooling Errors (2) and (3) of Table I. The new V_2 can be used to test the significance of both Vb and Vab. The variances of the 3 types of elementary comparisons considered before can be obtained by putting $\sigma_2 = \sigma_3$ in (3), (5) and (13). The altered results are

$$V(a_1 b_1 - a_1 b_2) = 2\sigma_2^2/r \quad .. \quad (16)$$

$$V(a_1 b_1 - a_2 b_1) = V(a_1 b_1 - a_2 b_2) = \frac{2}{r}\left(\frac{\sigma_1^2 + (q-1)\sigma_2^2}{q}\right) \quad (17)$$

It is easy to see that $a_1 b_1 - a_1 b_2$ can be tested by t with d. f. $= p(q-1)(r-1)$. But $a_1 b_1 - a_2 b_1$ and $a_1 b_1 - a_2 b_2$ can be tested only by d test for which Sukhatme's table should be entered with $n_1 = (p-1)(r-1)$, $n_2 = p(q-1)(r-1)$; and θ given by $\tan\theta = \sqrt{V_1 \; (q-1) \; V_2}$, V_2 being estimated by pooling the Errors (2) and (3) of Table I.

NUMERICAL EXAMPLE

For sake of illustration, I am giving below certain results taken from the previous Note (No. 26, of this series by S. Hedayetullah, S. Sen and K. R. Nair. We shall discuss the portion relating to varieties and dates of planting only of the year 1937-38, when we got significant values for the interaction between varieties and dates of planting. The mean yields for each variety and date of planting are given in Table II, figures excepting those in the margins being each based on average of 9 plots.

TABLE II

Mean yield of paddy per plot (9 ft. × 20 ft.) in tolas (Dacca Experiment, 1937-38)

Variety	Date of planting						Mean
	1 July	16 July	1 August	16 August	1 September	16 September	
1	728·44	780·00	698·44	540·00	406·89	354·44	584·70
2	618·22	592·22	618·44	473·33	460·67	256·00	503·70
3	584·44	576·44	549·33	451·56	406·22	203·55	461·93
Mean	643·70	649·56	622·07	489·41	424·59	271·33	516·78

The values of observed variances for each main effect and the interaction are given in Table III.

TABLE III

Results of analysis of variance

	D. F.	Variance	Ratio of variance
Blocks	2	72258·67	×
Varieties	2	210426·89	5·47
Error (I)	4	38492·11	×
Dates of planting	5	617315·36	25·27†
Error (II)	10	24433·10	×
Varieties × Dates	10	17287·81	2·55*
Error (III)	20	6778·20	×

* Indicates significance at 5 per cent point
† Indicates significance at 1 per cent point

It will be noted that Error (I) is greater than Error (II) and both much greater than Error (III). The first error is associated with the varietal strips and the second error associated with the strips for dates. The former strips are double the latter ones in size and hence Error (I) has become greater than Error (II).

Standard error for comparing yields of any two dates for a given variety is

$$\sqrt{\left[\frac{2}{9}\left(\frac{24433 \cdot 10 + 2 \times 6778 \cdot 20}{3}\right)\right]} = 53 \cdot 05$$

For $n_1 = 10$, $n_2 = 20$, $\tan\theta = \sqrt{\dfrac{24433 \cdot 10}{13556 \cdot 40}}$

$= 1 \cdot 80$ or $\theta = 60° \; 59'$

the value of $d_{5\%}$ from Sukhatme's Tables is 2·188.

A difference of 53·05 × 2·188 = 116·07 in the yield between two dates for a given variety should be judged as significant on the 5 per cent level.

Standard error for comparing yields of any two varieties for a given date is

$$\sqrt{\left[\frac{2}{9}\left(\frac{38492 \cdot 11 + 5 \times 6778 \cdot 2}{6}\right)\right]} = 51 \cdot 78$$

The smallest value of n_1 tabulated in Sukhatme's Tables is 6. But in our case $n_1 = 4$, $n_2 = 20$, $\tan\theta = \sqrt{\dfrac{38492 \cdot 11}{33891 \cdot 00}} = 1 \cdot 14$ or $\theta = 48° \; 38'$. The value of $d_{5\%}$ will be greater than 2·280 which is the value for $n_1 = 6$, $n_2 = 20$ and $\theta = 48°38'$.

In the present experiment the comparisons in which we are more interested are those which describe the properties of the yield-date curve for each variety, which may be graduated by a second degree parabola

$$y = A + B\xi_1 + C\xi_2 = a + bx + cx^2 \qquad (18)$$

where x = date of planting and y = mean yield per plot.

The values of the parameters involved in (18) are given in Table IV separately for each variety.

TABLE IV

Values of coefficients of the yield-date curve

Variety	A	B	C	*a*	*b*	*c*
1	584·70	—89·91	—12·97	778·88	0·84	—12·97
2	503·70	—67·07	—18·97	562·06	65·70	—18·97
3	461·93	—71·80	—18·68	539·47	58·98	—18·68

Standard errors of B and C are respectively given by

$$\sqrt{\left[\frac{2}{9\times 35}\left(\frac{24433\cdot 10+2\times 6778\cdot 20}{3}\right)\right]}=8\cdot 96\;;$$

and

$$\sqrt{\left[\frac{1}{336}\left(\frac{24433\cdot 10+2\times 6778\cdot 20}{3}\right)\right]}=6\cdot 14.$$

The value of d 5% for testing the significance of B and C is 2·188. The significant values of B and C must be greater than 19·60 and 13·43 respectively. We find that all the 3 values of B are highly significant; and that only the value of C got for variety 1, is just insignificant.

The standard error of the difference between any two values of B and any two values of C are given respectively by

$$\sqrt{\frac{4}{9\times 35}\times 6778\cdot 20}=9\cdot 28 \text{ and } \sqrt{\frac{1}{168}\times 6778\cdot 20}$$
$=6\cdot 35$

These differences can be tested by t. Values of t 5% for 20 degrees of freedom is 2·086. The critical differen ces for the B's and for the C's are 19·36 and 13·25 respectively. We find that the quadratic coefficients do not differ significantly but linear coefficients for varieties 1 and 2 are significantly different.

In conclusion, my thanks are due to Mr S. Raja Rao for help in the numerical work.

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DETERMINATION OF SODIUM BENZOATE IN PRESERVED CITRUS JUICES AND SQUASHES

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(With one text-figure)

SODIUM Benzoate is one of the preservatives commonly used in the preservation of juices and squashes. Its determination is consequently of great importance in the analysis of these products. A concentration of a thousand parts per million is permitted: but in practice, specially if used in combination with sulphur dioxide, it is seldom in excess of 500 p.p.m. In the course of determination of this preservative in some samples of citrus juices and squashes, sent to this laboratory by a leading firm of manufacturers, it was found that determination in concentrations of the order mentioned is not as accurate as would be desired for the purpose in view.

In the official A.O.A.C. method [1940] the sample is made alkaline to litmus and extracted with saturated salt solution. The residue is allowed to settle and the clear extract filtered. The filtrate is acidified and extracted with chloroform in a separating funnel to get the benzoic acid which is determined by titration against standard alkali, after evaporating the solvent. In practice this method was found to give too low results, which did not agree between themselves. For example, the samples mentioned above were supposed to contain 500 to 600 p.p.m. But the results in several replicates varied from 40 to 400 p.p.m. To ascertain whether any appreciable amount of the sodium salt is absorbed on the fruit cells, even in alkaline solution, a 100 gm. sample of orange juice containing 890 p.p.m. of benzoic acid was thoroughly ground with sand, salt being added at

the same time to saturate it, as directed in the A.O.A.C. method. This sample gave only 396 p.p.m. In case of unground sample the recovery was 320 p.p.m. The residue left on the filter paper in the latter case was ground with sand and washed with 150 c.c. water; but only an equivalent of 37 p.p.m. of benzoic acid was recovered from the filtrate. It is, therefore clear that the A.O.A.C. method is not suitable for the determination of benzoic acid used as a preservative in citrus juices and squashes. Other methods to which reference may be made are those of Illing [1932] and Mix [1939]. These depend on the volatility of benzoic acid in boiling acid solutions. But, on his own showing, Mix found a high variation (+16 per cent to —4 per cent) even in water solutions of sodium benzoate. The extraction is far more complicated in case of fruit juices and squashes when sugar and fruit cells are present in the mixture.

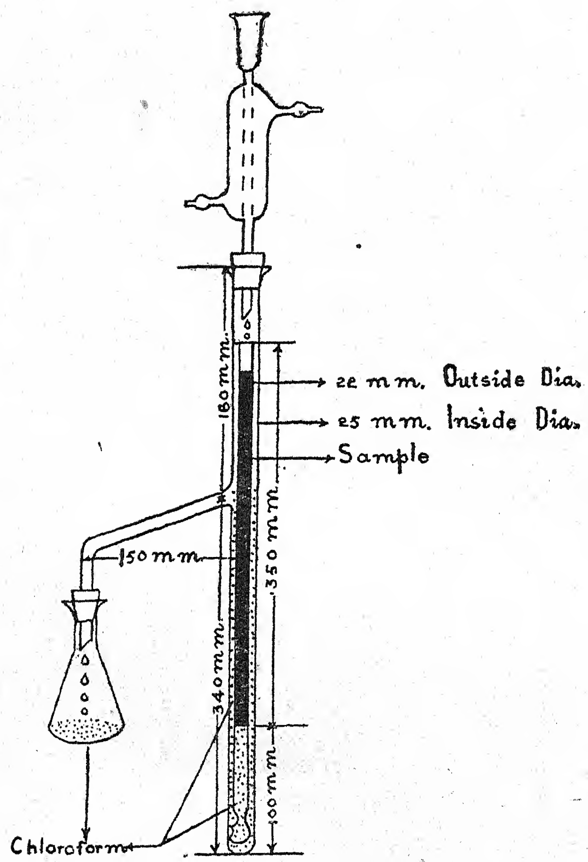

FIG. 1

A modified extraction method was, therefore, tried in which the apparatus shown in Fig. 1 was used. This apparatus is suitable for extracting 100 c.c. of the sample. It can be held in two clamps mounted on the same stand, thus facilitating removal from and to the water bath. The apparatus is charged with chloroform and 100 c.c. of sample acidified with 3 c.c. of strong hydrochloric acid are introduced into the inner tube through the long stemmed funnel. The chloroform rises into the outer jacket and some falls into the boiling flask. If necessary, more chloroform may be added through the same funnel. The reflux condenser is now fitted and the flask kept for boiling on a water bath. The boiling should be brisk so that the falling drops serve to shake the sample. If, as often happens, the fruit cells settle into a solid mass, this should be broken up once or twice with a long thin glass rod with a flattened end. As regards time of extraction it was found that two hours are not sufficient. Four and eight hours gave almost similar results and four hours are therefore recommended. The chloroform column below the sample should be at least 8 cm. long, otherwise there is risk of some droplets of the emulsion being carried to the boiling flask. At the end of the extraction the apparatus is taken off the water bath, cooled and the boiling flask removed. The sample is removed by suction through a long thin glass tube and the apparatus is ready for another extraction. The extract in the boiling flask is transferred to a separating funnel and washed with a little water, the flask and washing water being again washed with two portions of 5-10 c.c. chloroform. The chloroform solution and washings are collected in a flask and the solvent recovered by distillation till about 15 c.c. of the solution is left in the flask. This is transferred to a glass dish and the flask washed with 10 c.c. chloroform in two portions and the dish allowed to lie under a fan to evaporate the solvent. The residual benzoic acid is dissolved in neutral alcohol (85-90 per cent) and titrated with standard alkali, using phenelphthalein as indicator.

To test the accuracy of the method a sample of orange juice was separated into lots in which different amounts of sodium benzoate were added. Results of the replicate determinations of these samples are given in Table I.

Some of these juice samples and two samples of orange squash were analysed by both methods. The results in Table I show that whereas the A.O.A.C. method gives very low results, the method recommended gives only a slight variation. Statistical analysis of the results showed that the variation was not significant, and that the accuracy is unaffected by the change of concentration from 45 to 1800 p.p.m., the reaction being non-significant.

TABLE I

S.No.	Description of sample	No. of replications	Sodium benzoate mg. per litre (p.p.m.) Taken	Sodium benzoate mg. per litre (p.p.m.) Found (average)	Method used
1	Prepared in the laboratory by adding known amounts of sodium benzoate to fresh orange juice	2	44	39	New method
2	Ditto.	3	89	79	Do.
3	Ditto.	4	178	177	Do.
4	Ditto.	2	267	300	Do.
5	Ditto.	3	356	380	Do.
6	Ditto.	6	445	462	Do.
7	Ditto.	2	535	523	Do.
8	Ditto	3	668	627	Do.
9	Ditto.	4	713	712	Do.
10	Ditto	3	890	914	Do.
11	Ditto.	2	1340	1335	Do.
12	Ditto.	2	1780	1687	Do.
13	Ditto.	2	1780	1082	A.O.A.C.
14	Ditto.	2	890	320	Do.
15	'A' orange squash received from firm of manufacturers	2	500 to 600	352	Do.
16	'B' ,, ,, ,, ,,	2		324	Do.
17	'A' ,, ,, ,, ,,	2		540	New method
18	'B' ,, ,, ,, ,,	2		604	Do.

SUMMARY

The official A.O.A.C. method for the determination of benzoic acid is shown to be inaccurate for preserved citrus juices and squashes. A modified method is described in which the samples are placed in a long column and extracted for four hours. The formation of emulsion is avoided. The results obtained by this method are far more accurate and are not subject to variation due to change of concentration.

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STANDARDIZATION OF CURRY POWDERS

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(Received for publication on 13 May 1944)

ANALYSIS of several samples of curry powders, received in these laboratories from the Supply Department, showed that good deal of precise information on granularity, chemical standards and bacterial standards was necessary since general methods used in their preparation are very empirical. It was, however, recognized that rigid standards cannot be fixed unless extensive investigations were undertaken on condiments grown in different localities. Nevertheless, a few samples were analysed and have yielded interesting preliminary results. These results are presented under three heads, viz. (*a*) Physical test of granularity, (*b*) Chemical analysis, and (*c*) Micro-biological analysis.

MATERIAL AND METHODS

Six different samples of curry powders were obtained from different firms and were claimed by them to conform to the following recipe :

	Parts
(1) Turmeric	40
(2) Mustard	5
(3) Coriander	20
(4) Pepper (black)	5
(5) Chillies	10
(6) Common salt	3
(7) Cumin seeds	5
(8) Cloves	2
(9) Cinnamon	5
(10) Ginger	5

In addition to these six samples, a sample was prepared in the Laboratory and will be referred to in the text as 'Ls.'

Methods used in the analyses except in the case of physical test of granularity were standard methods [A. O. A. C., 1940 ; Tanner, 1932]. In the case of the granularity test, a modification of the technique used for cereal flours [Sterckx, 1939] was employed with success and will be described in detail under that head.

EXPERIMENTS AND RESULTS

A. *Physical test of granularity*

Two methods are usually employed for determination of the degree of granularity in cereal flours, (*a*) the sieving test, and (*b*) the sedimentation test. The former is essentially a comparative test and especially in the case of curry powders presents a serious difficulty in that the substance chokes the bolting silks due to a high oil content. The latter method has been suggested by Sterckx [1939] wherein flour is suspended in a mixture of petroleum ether (40°—60°C. boiling point) 90 per cent and acetone 10 per cent and the mixture poured into a burette of stated dimensions containing the same liquid. The particles sink and stratify in different layers. Sterckx sums up by saying 'the method is open to considerable amount of experimental error when used by different operators '. This sedimentation method has been tried here in the case of curry powders with a few modifications. A 5 gm. sample of the curry powder contained in a shallow porcelain dish was suspended in about 10 c.c. of petroleum ether and acetone mixture (as given above) and quickly poured into an ordinary 50 c.c. (1/10 c.c.) burette containing a column of mercury in the bottom up to the 40 c.c. mark. The rest of the powder adhering to the dish was also washed down the burette with a fine jet of the mixture from a wash bottle. More of the mixture was poured into the burette till the level rose up to 0·0 c.c. The burette was left undisturbed for about an hour after which the reading in c.c. was taken of the different layers occupied by the different particles of powder. The line of demarcation between particles of different sizes was particularly clear between the 'coarse' and the 'fine particles', although with a little experience it was not difficult to distinguish between very coarse, coarse, fine and very fine particles. However, the result obtained in these experiments seem to be very consistent if viewed as to categories, viz. 'coarse' and 'fine'.

The use of a column of mercury as done here seems to be beneficial, firstly in that the particles are kept in a form of agitation as soon as they are poured in and not allowed to quickly settle down as happens in the case where no mercury is used and it is obvious that a speedy sedimentation of the coarse particles would influence that of the fine ones ; secondly the miniscus of the mercury permits of accurate reading of the burette. It may be emphasized that three precautions are necessary for consistent results ; firstly, the quick transference of the mixture and powder into the burette; secondly the need for a burette with very clean walls and lastly, the temperature of the room should be far below that of the boiling point of the

petroleum-ether, otherwise large bubbles of air appear in the settling layers and adversely affect the result.

The results obtained with seven samples of curry powders are presented in Table I.

The results seem to permit of the following conclusions when 5 gm. samples were used for the test.

(*a*) Coarse and very coarse particles should have sedimentations volumes not less than 5·00 c.c. and not more than 7·00 c.c.

(*b*) Fine and very fine particles should have sedimentation volumes not less than 3·00 c.c. and not more than 4·00 c.c.

(*c*) The total volume occupied by any one sample should not exceed 10 c.c.

Sample No. 6 is definitely very coarse and does not conform to these standards. Similarly sample No. 3 has more of coarse and less of fine particles.

TABLE I

Granularity test of curry powders

Sample No.	No. of gm. of sample used for the test	Total No. of c.c. occupied by sample in burette	Sedimentation volumes in c.c. occupied by the different strata of sample	
			'Coarse particles'	'Fine particles'
1	5·0	9·85	6·25	3·60
2	5·0	9·75	6·00	3·75
3	5·0	10·15	7·55	2·60
4	5·0	9·20	5·55	3·65
5	5·0	9·85	6·75	3·10
6	5·0	15·10	10·55	4·55
Ls*	5·0	8·80	5·00	3·80

*Ls stands for Laboratory prepared sample

TABLE II

Chemical analyses of curry powder

Sample No.	Moisture per cent	Total ash per cent	Ash soluble in HCl per cent	Ash insoluble in HCl per cent	Alkalinity of ash as c. c. of N/10 HCl reqd. for ash of 100 gm.	Cold water extract per cent	Alcoholic extract per cent	Volatile ether extract per cent	Non-volatile ether extract per cent	Crude fibre per cent	Nitrogen per cent	Nx 6·25 per cent protein	NaCl per cent
1	7·58	10·26	9·68	0·58	76·00	24·12	19·46	4·09	11·91	9·21	1·60	10·00	6·13
2	5·76	9·01	8·24	0·77	79·00	19·91	18·90	3·95	12·82	11·20	1·76	11·00	3·85
3	4·97	11·26	9·43	1·83	91·00	20·09	14·84	3·62	12·41	11·20	1·38	8·62	4·38
4	7·26	21·48	20·16	1·32	81·00	27·61	19·12	4·76	7·16	7·36	1·45	9·06	14·88
5	7·89	6·94	5·99	0·95	95·00	11·49	10·70	4·57	11·38	11·86	1·51	9·45	1·75
6	13·58	4·72	4·22	0·50	94·00	26·10	9·40	2·36	7·69	12·67	1·72	10·76	0·70
Ls*	7·90	8·68	8·06	0·62	82·00	16·05	15·62	2·56	12·90	10·05	1·47	9·19	3·50

*Ls sample prepared in the Laboratory

B. Chemical analysis

The number of samples chemically examined are small and not much attempt will be made to draw general conclusions. Nonetheless, it could be seen from Table II that the total ash figure in sample 4 is high and is due to the abnormally high value of sodium chloride. Sample 6 shows a rather high percentage of ash insoluble in HCl as compared with the others. Samples 5 and 6 are rather low in sodium chloride. Sample 'Ls' (prepared in the laboratory) appears to be one of the best samples, as also Nos. 1 and 2, although No. 1 has a rather high sodium chloride figure.

C. *Micro-biological analysis*

Condiments that make up curry powder are bound to have a mixed flora of organisms, but it was thought that some idea should be obtained by conducting the analysis. Standard methods have been used [Tanner, 1932] and the bacterial numbers presented in Table III were as ascertained by the agar plate method (using 1·0 per cent malt agar) and also checked by counts made with Thoma's Haemacytometer. No attempt was made to identify the organisms. All the organisms belong to the aerobic group and more often than not showed pleomorphism. Fermentation of 1·0 per cent malt solution at 37°C. resulted in gas production. But when the curry powder was boiled in water for 5 min. it gave negative results (Table III). Since curry powder is usually consumed after cooking this procedure was adopted to ascertain the resistance of the organisms to boiling treatment. An interesting

TABLE III

Micro-biological analysis of curry powders

No. of sample	No. of bacteria per gram of sample		Description of bacteria	Fermentation test in 1·0 per cent Malt solution at 37°C .of		Mould fragments
	No. in fresh sample	No. in sample 2 months old		Fresh sample	After boiling in water for 5 min.	
1	400,000	100,000	Short rods and coccus forms	Positive .	Negative .	Totally absent
2	310,000	110,000	Few rods and mostly coccus forms	Do. .	Do. .	Do.
3	800,000	250,000	Short rods, spore-formers	Do. .	Do. .	Few fragments seen. Number as counted by cytometer not more than 20 per gram of sample.
4	54,500	17,500	Do. . .	Do. .	Do. .	Totally absent
5	155,000	60,000	Short thick rods, profuse spore-formers	Do. .	Do.	Do.
6	320,000	100,000	Do. . .	Do. .	Do.	Do.
Ls*	160,000	75,000	Do. . .	Do. .	Do. .	Do.

*Ls sample prepared in the Laboratory

change in the initial flora was seen when bacterial counts were made after two months' storage of the curry powders (Table III). In all the samples analysed the number of viable colonies was reduced by at least two thirds. This gradual fall of the microbial numbers has been noticed in the cases of dried vegetables and fruits [Tanner, 1932] where the moisture content was below 10·0 per cent. In Table II, moisture content of all the seven samples analysed, with the exception of sample 6, is below 10·0 per cent. Curry powders and other condiments have a low moisture content and in addition present an unfavourable growth medium for microbial activity as compared with dried vegetables and fruits. It can be observed that the bacterial counts in these samples are well within the maximum standards set up for Barley malt, Rye malt and many other cereals [Tanner, 1932] and since curry powders are usually cooked with vegetables their microbial flora presents no serious difficulty and does not affect the safety of the product for human consumption.

SUMMARY

1. Seven samples of curry powders have been analysed physically (for granularity), chemically and micro-biologically.

2. A modification of the granularity test used in cereals by sedimentation of known weight of the powders in a burette containing a mixture of petroleum ether and acetone has been evolved. A fairly dependable stratification of particles of different sizes has resulted and the limitation of coarse *versus* fine particles for a good sample is given.

3. Chemical analyses have shown that percentage of total ash rises in a sample with high sodium chloride figure. Other figures for moisture, volatile extract, crude fibre, etc. have been determined in all the seven samples analysed.

4. Micro-biological analyses showed a mixed bacterial flora and the counts taken after two months' storage showed a marked fall in numbers over that present in the fresh sample. The bacterial counts recorded are well within the standard limits fixed for Barley malt, Rye malt and other cereals.

ACKNOWLEDGEMENT

Our thanks are due to Sardar Bahadur Lal Singh, Fruit Specialist, Punjab, for his suggestions and criticisms during the course of this investigation, and to the Imperial Council of Agricultural Research, for research grant which has enabled us to undertake this investigation at the instance of the Supply Department, Government of India. We are also indebted to Mr Nagina Lal, Research Assistant, for the assistance rendered in collecting the chemical data.

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ERRATA

For the remarks in the last column of Table III on page 636 of the December 1943 No. of the Indian Journal of Agricultural Science substitute as follows :

Methods	Year	Remarks
Sweeping	1937 . .	L. S. S., 4F, 43F, 100F, K25
	1938 . .	Jubilee, L. S. S., 4F, 43F, 100F, K. 25
	1939 .	4F, L. S. S., 100F, 43F, 124F, K. 25
	1940 . .	4F, A. C. 31, 43F, L. S. S., 186F, K. 25, 126F
	1941 . .	199F, 148F, 43F., L. S. S., 4F, 124F, K. 25
Counting	1937 . .	L. S. S., 4F, 43F, 100F, K. 25
	1938 . .	Jubilee, L. S. S., 4F, 43F, 100F, K. 25
	1939 . .	4F, L. S. S., 100F, 43F, 124F, K. 25
	1940 . .	4F, L. S. S., 43F, 186F, A. C. 31, 126F, K. 25
	1941 . .	148F, 43F, 199F, L. S. S., 4F, 124F, K. 25
Fumigation	1937 . .	L. S. S., 4F, 43F, 100F, K. 25
	1938 . .	Jubilee, L. S. S., 4F, 43F, 100F, K. 25

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ORIGINAL ARTICLES

STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

XIII. MANURING OF COTTON*

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(Received for publication on 23 November 1943)

(With Plate XI)

MANURING of cotton as of other crops is one of the basic problems in agriculture and forms an important part in any programme for crop improvement. Previous work done in the Punjab revealed that applications of phosphate and potash to cotton proved ineffective while the response to nitrogen varied from place to place and season to season [Vaidyanathan, 1934, and Dept. of Agriculture, Punjab, 1936]. In certain cases the response was spectacular, in others meagre. These findings were important inasmuch as they suggested the elimination of the two major nutrients, phosphates and potash, from any manurial programme, but they were of restricted value as no definite conclusion could be arrived at with respect to nitrogen application as a general practice. The causes for the variations in the utility of nitrogenous manures ought to be explained before they could be recommended for wide adoption.

The low nitrogen status of the soils in India gave Crowther [1939] the impression of great prospects of the use of the sulphate of ammonia in this country. Experience in the Punjab has, however, shown that low nitrogen content of the soil is not always attended with high response to this fertilizer in case of cotton. The success or the failure of manuring depends not only on the knowledge of the nutrient limiting but also on the controlling influence of the other factors associated with it. These factors may be different in the different countries and hence require independent study.

It has already been pointed out [Dastur, 1941] that deficiency of nitrogen produces *tirak* symptoms in the Punjab-American cottons on light sandy soils. The effect of nitrogen application as sulphate of ammonia, in combination with varying levels of other factors, was therefore studied on the different soil types, in a large number of complex experiments conducted during 1937-1942 in the course of *tirak* investigations. The results of some of the experiments showing the effect of nitrogen on the various phases of plant activity on light sandy soils have since been reported [Dastur and Mukhtar Singh, 1943, 1944]. The present contribution is devoted to a concise account of the practical aspects of cotton manuring based on the results of the numerous experiments distributed over the important American-cotton growing tracts of the province.

INVESTIGATION

In all about 40 replicated field trials on lands representing different soil conditions were conducted. Nearly 60 per cent of them were carried out on the Departmental Agricultural farms and the rest at private estates. The experiments were mainly of the multiple-factor type. Sowing date as a factor was introduced in bulk of the trials as preliminary studies had shown this factor to greatly influence the yield and the boll opening of cotton. A few experiments also included spacing types. The relation of nitrogen with other factors such as variety, watering, phosphorus, potash, etc. was also explored. Some experiments also provided information as to the time of application, the levels, and the forms of nitrogen.

Relevant information pertaining to the individual experiments and the nature of the soil under them is consolidated in Table I (A and B). In majority of cases, soil samples were taken before the experiments were laid out and were later analysed to determine the nature of soil conditions. In a few cases, however, the characteristic symptoms of the plants and the texture of the surface soil broadly indicated the soil type.

* The investigations described in this paper were carried out in the Punjab Physiological (Cotton Failure) Scheme financed jointly by the Indian Central Cotton Committee and the Punjab Government

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The yields of the control and the manured plots, averaged over all levels of the remaining factors, and the mean response to nitrogen along with appropriate standard errors are also given in the last three columns of the table. The experiments have been grouped according as : (A) the increase in yield with nitrogen was high or medium and definitely profitable, (B) the response was low or nil involving monetary loss. The price of the sulphate of ammonia has been taken at its pre-war rate of Rs. 5 per maund (82·2 lb.) and that of seed cotton at its lowest value of Rs. 7 per maund.

TABLE I (A)

Experiments in which the response to the sulphate of ammonia was high and profitable

Expt. No.	Station	Year	Soil type	Previous crop	Factors studied in addition to nitrogen	Dose of sulphate of ammonia with time of application	Yield of *kapas* in maunds per acre	Response over control	S. E. of response
1	Lyallpur Agricultural Farm	1937	Light sandy	Fallow	Phosphorus, potash, F.Y.M., watering	Control 1½ md. at sowing + 1½ md. at flowering	19·25 22·74	 3·49**	0·55
2	Ditto.	1938	Ditto.	Oilseeds	Phosphorus, potash, watering	Control 3 md. at sowing 3 md. at flowering 3 md. at sowing + 3 md. at flowering.	12·86 20·96 22·11 25.82	 8·10** 9·25** 12·96**	1·03
3	Ditto.	1939	Ditto	,,	Sowing date, spacing, watering	Control 3 md. at flowering	7·94 13·95	 6·01**	0·49
4	Ditto.	,,	Light sandy with alkaline subsoil	,,	Sowing date, organic manures	Control 1½ md. at sowing + 1½ md. at flowering.	4·31 7·50	 3·19**	0.88
5	Ditto.	,,	Light sandy with mediumly saline subsoil	,,	Phosphorus and potash, sowing date, variety, spacing	Control 1½ md. at flowering.	9·94 13·26	 3·32**	0·32
6	Ditto.	1940	Light sandy with alkali patches	,,	Sowing date, variety, time of application	Control 1 md. 2 md. 3 md.	8·52 9·52 11·34 13·27	 1·00 2·82* 4·75**	1·19
7	Ditto.	1941	Light sandy	,,	Sowing date, variety, spacing	Control 3 md. at sowing 3 md. at flowering	16·89 22·25 22·14	 5·36** 5·25**	0·46
8	Ditto.	,,	Ditto.	Wheat	Sowing date, variety, watering	Control 3 md. at flowering	9·87 18·44	 8·57**	0·25
9	Ditto.	,,	Ditto.	Oilseeds	..	Control 3 md. at sowing 6 md. at sowing	17·63 25·21 25·31	 7·58** 7·68**	0·80
10	Ditto.	1942	Ditto.	,,	F.Y.M., molasses	Control 3 md. at flowering	15·58 18·68	 3·10**	0·45
11	Ditto.	,,	Ditto.	,,	Sowing date	Control 2 md. at sowing 4 md. at sowing 2 md. at flowering 4 md. at flowering	7·64 10·58 12·27 10·48 12·54	 2·94** 4·63** 2·84** 4·90**	0·65
12	Sargodha New Seed Farm	1940	Light sandy with saline subsoil	,,	Sowing date, variety, watering	Control 2 md. at flowering.	8·52 10·53	 2·01**	0·53
13	Ditto.	1941	Ditto.	,,	Sowing date, variety	Control 2 md. at flowering	9·36 12·26	 2·90**	0·57
14	Abdul Hakim (Multan)	1939	Light sandy soil with saline patches	Cotton	Sowing date, variety, watering	Control 2 md. at flowering	9·55 14·34	 4·79**	0·41
15	Multan Agri. Farm	1941	Light sandy	Wheat	Sowing date, variety, spacing	Control 2 md. at flowering	9·50 15·00	 5·50**	0·84
16	B. C. G. A. Farm, Khanewal (Multan)	1942	Light sandy with saline subsoil and *kalar* patches	Cotton	Phosphorus, potash, sowing date	Control 2 md. at flowering	17·05 19·15	 2·10**	0·55
17	S. B. S. Ujjal Singh's Farm, Mian Channu (Multan)	,,	Light sandy with saline subsoil	Gram following reclamation by rice	Sowing date, variety	Control 2 md. at sowing 2 md. at flowering	8·82 10·40 11·98	1·58** 3·16**	0·49
18	Convillepur Farm (Montgomery)	1940	Ditto.	Gram, Berseem, Wheat	Sowing date, variety	Control 2 md. at flowering	14·03 16·84	 2·81**	0·57
19	Military Farm, Okara (Montgomery)	1942	Ditto.	Cotton	Phosphorus, potash, sowing date	Control 2 md. at flowering	11·84 15·17	 3·33**	0·39
20	Iqbalnagar Estate (Montgomery)	,,	Light sandy	,,	Sowing date, variety, organic manures	Control 3 md. at flowering	15·59 18·33	 3·24**	0·67

TABLE I (B)

Experiments in which the response to sulphate of ammonia was low involving monetary loss

Expt. No.	Station	Year	Soil type	Previous crop	Factors studied in addition to nitrogen	Dose of sulphate of ammonia and the time of application	Yield of *kapas* in maunds per acre	Response over control	S. E. of response
21	Lyallpur Agricultural Farm	1937	Light sandy with saline subsoil	Oilseeds	..	Control . 3 md. after sowing	4·17 5·03	0·86	0·90
22	Ditto.	1938	Ditto.	Cotton	Potash, presowing watering, organic manures	Control . 1½ md. before sowing + 3 md. at flowering	7·64 11·25	3·61*	1·51
23	Ditto.	,,	Sandy loam with saline subsoil	Fallow	Sowing date, organic manures	Control . 3 md. at sowing	21·20 22·95	1·75	2·16
24	Ditto.	1939	Ditto.	Cotton	Organic manures	Control . 1½ md. at sowing + 1½ md. at flowering	4·01 5·10	1·09	2·82
25	Ditto.	,,	Ditto.	Fallow	Sowing date, watering spacing	Control . 3 md. at flowering	13·82 13·41	—0·41	1·06
26	Ditto.	1941	Ditto.	Cotton	Phosphorus, potash	Control . 2½ md. at flowering	21·66 22·89	1·23	3·03
27	Ditto.	1942	Ditto.	,,	Sowing date	Control . 3 md. at flowering	15·09 15·68	0·59	0·66
28	Ditto.	,,	Light sandy with saline subsoil	,,	Organic manures	Control . 3 md. at flowering	8·82 10·77	1·95	1·48
29	Pirmahal, 680/21 Chak (LYP)	1939	Saline subsoil	Sorghum	Sowing date	Control . 2 md. at flowering	6·9 7·6	0·7	..
30	Brucepur Farm (Lyallpur)	1940	Sandy loam with saline subsoil	Fallow, gram	Sowing date, variety, watering	Control . 2 md. at flowering	14·52 15·67	1·15	1·02
31	B. C. G. A. Farm, Khanewal (Multan)	1939	Light sandy with saline subsoil and *kalar* patches	Cotton	Sowing date, watering	Control . 2 md. at flowering	1·48 1·68	0·20*	0·09
32	Ditto.	1940	Ditto.	Wheat	Sowing date, variety, watering	Control . 2 md. at flowering	13·35 15·13	1·78**	0·55
33	Ditto.	1941	Ditto.	Fallow	Phosphorus, potash, sowing date	Control 2 md. at flowering	6·57 7·40	0·83**	0·22
34	Military Farm, Okara (Montgomery)	1939	Ditto.	*Toria*, gram, berseem	Sowing date, watering	Control 1·9 md. at flowering	4·36 4·94	0·58	
35	Ditto.	1941	Ditto.	Cotton	Phosphorus, potash, sowing date	Control . 2 md. at flowering	9·20 10·69	1·49**	0·26
36	Montgomery (Chak 90/9L)	1939	Highly saline subsoil	,,	Sowing date, watering, variety	Control 2 md. at flowering	7·08 7·95	0·87**	0·29
37	Montgomery Agricultural Farm	,,	Highly saline subsoil with patches of *kalar*	,,	Sowing date, watering	Control . 3 md. at flowering	1·32 1·42	0·10	0·17

A study of the results given in Table I (A & B) will show that the response to manuring with sulphate of ammonia on yield was high and profitable in 20 experiments while it was low and unprofitable in the remaining 17 experiments. Thus chances for the success and the failure of manuring cotton in the Punjab were found to be nearly equal.

It could also be seen from Table I that the increase in yield obtained by the application of a unit dose of sulphate of ammonia was not governed by the general yielding capacity of a field. Fields producing as low as 1 to 5 md. of *kapas* per acre have either not responded to manuring or have given a low response (Expts. 21, 24, 29, 31, 33, 34, 37), while fields with a higher yielding capacity have been found to give high and profitable returns with the application of sulphate of ammonia (Expts. 2, 3, 7, 8, 9, 14, 15). Thus the level of yield in a field was no index for manuring of cotton in the Punjab. It indicated that soil factors other than nitrogen status of the soil operated in determining the response to manuring. The investigations carried out in the Punjab Physiological (Cotton Failure) Scheme have made it possible to distinguish the soil conditions where manuring would be profitable and where it would involve monetary loss.

Soil conditions

A study of the soil in several parts of the Punjab in relation to the effect produced by the sulphate of ammonia on the growth and yield of cotton revealed that on light sandy soils free from subsoil salinity or alkalinity a very heavy response to manuring was obtained. The response was particularly high if the cotton followed wheat or an oilseed crop (Table IA). The increase in yield was of a medium order if such fields were allowed to recuperate through fallowing (Expt. 1).

Salinity or alkalinity or high *p*H in the subsoil was found to affect adversely the response to manuring. Although the fields having these subsoil conditions differed widely in their yielding capacity without manuring, the application of sulphate of ammonia was found to be unprofitable in all cases (Table IB). This held good for the organic manures as well (Table VIII).

The above two soil conditions are found irregularly distributed in the cotton fields. Fields with light sandy soil may also possess patches of subsoil salinity or alkalinity in varying proportions. The average increase in yield by manuring such a field would, therefore, depend on the relative proportion of such areas present in the subsoil. The variations in response to manuring can be partly understood in the light of the above findings. It also indicates why a general recommendation for manuring of cotton in the Punjab could not be made as was done for Egypt by Crowther *et al.* [1937]. Other relevant factors found to influence the response to manuring on light sandy soil are briefly mentioned below:

Varieties

Whereas the *desi* variety, Moll. 39 (*G. indicum*) gave a high and profitable response to nitrogen on all soil types, the ability of the Punjab-American cottons (*G. hirsutum*) to give such increases in yield with manuring was greatly restricted by the subsoil conditions (Table II).

Another important fact that emerged from this study was that the response to nitrogen on the different varieties varied in the order of their yielding capacity. Of all cottons, Moll. 39 gave the maximum yield as well as the highest response to nitrogen in all cases except in Expt. 14 where the germination and the subsequent stand of this variety was poor on account of patches of alkali on the soil surface.

L.S.S. yields were heavier than 4F and the response to nitrogen was also found to be greater in the former than in the latter (Expts. 7, 12, 13). The remaining strains, viz. 289F/43, 289F/K25 and 289F/124 did neither differ significantly in their yielding capacity nor in their responsiveness to nitrogen.

Sowing time

The sowing time of cotton was another factor that governed the response to manuring. It was found that generally May-sown crop gave higher increases in yield by manuring than the June-sown crop (Table III). The reduction in the magnitude of response was specially marked in the crop sown during the second half of June. If the soils were extremely deficient in nitrogen as in Expts. 14, 15, 17 and 18, all the sowings gave equally pronounced increases in yield by manuring. With higher doses of sulphate of ammonia on such fields the same relationship of sowing time with nitrogen application would have probably held good. As June sowings of American cottons have now been recommended as a preventive measure against *tirak*, this aspect of manuring must be clearly borne in mind.

TABLE II

Increase in yield with the sulphate of ammonia under different varieties and its relation to their yielding capacity

Expt. No.	Dose of manure at flowering (md. per acre)	Increase in yield with manure (md. per acre)						S.E.	Order of varietal mean yields
		Moll. 39	4F	L.S.S.	289F 43	289F K25	289F 124		
5 (Lyallpur)	1½	3·98*	2·66**	..	..	..	..	0·45	Moll. 39>4F
7 ,, ...	3	..	5·28**	5·56**	4·89**	..	..	0·80	L.S.S.>4F>43F
8 ,, ...	3	10·66**	6·47**	..	..	..	..	0·36	Moll. 39 > 4F
12 (Sargodha) . .	2	4·00**	1·48	2·36*	0·22	..	..	0·95	Moll. 39 > L.S.S. > 4F>43F
13 ,, ...	2	..	1·80*	3·99**	..	..	..	0·81	L.S.S > 4F
14 (Multan)	2	3·43**	6·16**	..	..	..	..	0·58	4F > Moll. 39
15 ,, ...	2	..	..	..	4·14**	7·35**	5·01**	1·45	Varieties and varieties × nitrogen insignificant
17 ,, ...	2	..	..	..	3·08**	3·43**	2·97**	0·84	
18 (Montgomery)	2	5·78**	..	..	2·34**	0·30	..	0·82	Moll. 39 > 43F > K25
20 ,, ...	3	..	..	..	5·17**	..	3·32**	0·82	Varieties insignificant
30 (Lyallpur)	2	2·49	..	0·92	0·05	..	..	1·33	Moll. 39 > L.S.S. > 43F
32 (Multan)	2	3·75**	..	..	0·79	0·78	..	0·98	Moll. 39 > K25 > 43F
36 (Montgomery) . .	2	1·22**	0·54	..	..	..	..	0·29	Moll. 39 > 4F

TABLE III

Variation in yield response to the sulphate of ammonia with changing sowing date

Expt. No.	Dose of manure at flowering (md. per acre)	Increase in yield with manure (md. per acre)				S.E.
		1—15 May	16—31 May	1—15 June	After 15 June	
3	3	(12 May) 7·85**	..	(2 June) 6·88**	(22 June) 3·29**	0·85
4	1½+ 1½ at sowing . .	(1 May) 4·36**	..	(1 June) 2·03	..	1·25
5	1½	(6 May) 4·08**	..	(10 June) 2·55**	..	0·45
6	3	(10 May) 5·37**	(28 May) 5·84**	(15 June) 3·03*	..	1·27
7	3	(15 May) 6·89**	(31 May) 5·05**	..	(20 June) 3·79**	0·80
8	3	(15 May) 9·22**	..	(10 June) 7·91**	..	0·36
11	2	..	(21 May) 4·85**	(11 June) 2·45*	(2 July) 1·21	1·13
11	4	..	(21 May) 7·70**	(11 June) 5·21**	(2 July) 1·80	1·13
12	2	(15 May) 2·87**	(30 May) 3·85**	(15 June) 1·41	(30 June) 0·08	1·06
13	2	(15 May) 3·83**	..	(2 June) 3·25**	(19 June) 1·60*	0·81
14	2	..	(18 May) 4·67**	..	(18 June) 4·93**	0·58
15	2	..	(19 May) 4·51**	(6 June) 4·95**	(24 June) 7·04**	1·45
16	2	..	(20 May) 2·46**	..	(20 June) 1·73*	0·77
17	2	..	(18 May) 4·02**	(12 June) 2·05*	(28 June) 3·41**	0·84
18	2	(8 May) 3·15*	(23 May) 2·50*	(7 June) 3·52**	(22 June) 2·05	1·14
19	2	(13 May) 4·50**	..	..	(20 June) 2·18**	0·55
20	3	..	(20 May) 5·24**	(7 June) 2·31*	(27 June) 2·19	1·15

Spacing

There was an indication that for manurial response May-sown crop behaved indifferently to spacing, but close spacing was specially conducive to better fertilizer response in the case of June-sowings. The experimental evidence in favour of this view is, however, still not conclusive.

Watering

Heavy watering greatly favoured the effectiveness of manure in Expt. 1 where the field was allowed to recuperate through fallowing prior to sowing cotton. Under intensive system of cropping, however, nitrogen alone acted as a limiting factor and the increases in yield with the artificial fertilizer were so heavy under normal watering that further improvement in response through extra dose of water was meagre (Expts. 2, 3, 8, 14). Hence heavy watering on nitrogen deficient soils would not be of much benefit whether given with or without the application of a nitrogenous fertilizer.

Time of application

Optimum time for the application of the sulphate of ammonia was unmistakably mid-August for the May-sown cottons. This confirms the previous experience in the Punjab. The differences in favour of August application were less marked as the sowings were delayed, so much so that in a few cases (Expts. 7, 11) application before sowing proved slightly superior for the late sowing.

Dose of manure

There were only a few trials involving the comparisons of the different doses of ammonium sulphate. A study of Table I reveals that the increase in yield is linear up to 3 md. of manure per acre (Expt. 6). The response trend shows a decline with higher rates of application (Expt. 11), and 6 md. of sulphate of ammonia is undoubtedly an over doze (Expts. 2, 9). In the experiments under review, the dose employed was 2-3 md. The results obtained and discussed, therefore, are of general practical value.

Effect of phosphatic and potassic fertilizers

There were seven trials to study the effect of the fertilizers with and without nitrogen. Two experiments were repeated on the same sites to find out the residual effect, if any. In spite of the heavy doses used, the direct as well as the residual effects of these fertilizers were insignificant in all cases (Table IV). In view of these results and those already obtained by the Department of Agriculture, it can safely be concluded that the Punjab soils do not lack in phosphorus or potash. Besides, none of these fertilizers interacted with nitrogen the level of which alone determined the final yield.

Table IV

Effect of phosphorus and potash on the yield of cotton

Expt. No.	Dose of phosphate lb. P_2O_5 per acre	Dose of potash lb. K_2O per acre	Yield of *kapas* in maunds per acre				S.E. of mean
			Control	Phosphorus	Potash	Phosphorus + Potash	
1	120	48	20·3	21·7	20·6	21·4	0·55
2	100	200	20·4	19·9	20·7	20·8	0·73
5	50	50	11·2	..	..	12·0	0·38
22	..	360	8·98	..	11·2	..	1·07
26	100	200	22·5	22·4	21·7	22·4	3·03
33	200	230	7·44	6·95	6·99	6·56	0·69
35	200	230	10·8	9·25	9·44	10·3	0·44
16	Residual effect of Expt. 33	..	17·6	17·8	19·1	17·9	1·17
19	Residual effect of Expt. 35	..	13·0	13·5	13·8	13·7	0·63

Effect of organic manures

Farmyard manure and berseem green manure were tried in a few experiments. The results are summarized in Table V. The absence of response in Expt. 1 was attributable to three factors, viz. (1) cotton followed cultivated fallow, (2) the dose was small, and (3) this treatment was relegated to the main plots. The soil under Expts. 23, 24 being sandy loam and saline was responsible for the failure of response to manuring. In other experiments the increases in yield were substantial as the soil underneath was light and sandy. Thus these manures behaved in the same manner as did the sulphate of ammonia in relation to soil conditions.

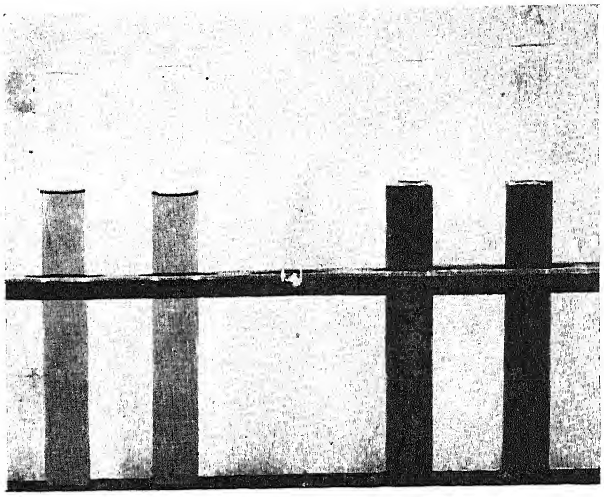

FIG. 1. The photograph of leaf extracts giving the negative 'tannin' reaction (left) and positive 'tannin' reaction (right)

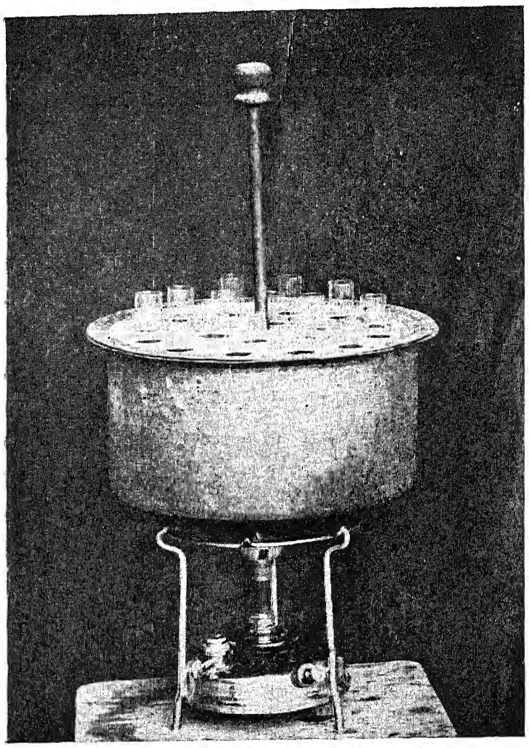

FIG. 2. The apparatus for preparing leaf extract for tannin test. 16 samples can be extracted at a time by means of this apparatus.

TABLE V

Effect of Farmyard manure and berseem green manure on the yield of cotton

Expt. No.	Dose (tons per acre)	Yield of *kapas* in maunds per acre			Response	S.E.
		Control	Farm yard manure	Berseem green manure		
1	5	20·7	21·3	..	+0·6	0·78
4	10	4·31	..	7·31	+3·0**	0·88
10	20	13·4	22·6	..	+9·2**	0·90
22	20	7·64	11·86	10·05	{ 4·22** 2·41	1·51
23	10	21·2	19·5	..	—1·7	2·16
24	10	4·01	..	3·41	—0·60	2·82

On account of the non-availability of the sulphate of ammonia under the present war situation, the comparative manurial value of oil-cakes and ammonium sulphate was studied in the year 1942. Quantities of manures to supply 50 lb. N per acre were calculated and added. *Toria* cake though slightly inferior to the sulphate of ammonia on equivalent nitrogen basis proved to be a good substitute for the latter (Table VI). Cotton cake did not hold out promise of extensive use. There was an indication from Expt. 38 that *toria* cake should preferably be applied before sowing. Further work is, however, necessary to confirm these findings and to work out the economics of *toria* cake.

TABLE VI

Comparative effects of ammonium sulphate and oil-cakes on the yield of cotton

Expt. No.	Time of application of oil cakes	Yield of *kapas* in maunds per acre				S.E. of mean
		Control	*Ammonium sulphate	*Toria* cake	Cotton cake	
10	At flowering	13·24	17·02	16·10	..	0·38
20	At sowing	15·59	18·83	17·69	16·64	0·35
28	Ditto.	8·82	10·77	9·57	8·14	1·04
38 (*a*)	Ditto.	11·24	..	16·29	..	0·33
38 (*b*)	At flowering	..	..	15·87	..	..

* Applied in all cases at flowering in the middle of August

A PRACTICAL METHOD FOR DETECTING NITROGEN-DEFICIENT FIELDS

Manuring of American cottons in the Punjab could be profitably undertaken on light sandy soils free from subsoil salinity. This finding could not be put to practical use as it was impossible for a zemindar to know the soil conditions and to exclude from manurial programme such fields as were not likely to yield profitable returns. Besides, the yielding capacity of a field was shown to be no criterion for manuring it. During the course of investigations carried out in the Punjab Physiological Scheme, a simple and inexpensive method has been found to detect cotton-fields which would give profitable increases in yield by manuring with ammonium sulphate. This method is termed as 'tannin test', and is described below:

In the month of August six cotton plants are selected at random from one-fourth of an acre and 30 discs are cut out from mature leaves by means of a leaf punch. They are transferred to a tube containing about ½ oz. of water and the tube is kept for 2 hr. in a hot water bath. When the extract of the leaf discs cools down, it is treated with 5 drops of an aqueous solution of osmic acid (1 gm. of osmic acid dissolved in 4½ lb. or 2 litres of water). Two drops of dilute sulphuric acid are then added to the extract. If a blue green to a dark brown colour (Plate XI, fig. 1) is produced, the crop requires nitrogen manuring. If the leaf extract remains yellow or orange-red, manuring is not necessary. Apparatus required to handle 16 samples at a time is given in Plate XI, fig. 2. The cost of making this test works out to be about one anna per sample at the pre-war rates of the chemicals, etc. used.

'Tannin test' has been tried out extensively for three successive years on the fields of zemindars in the different cotton-growing tracts of the Punjab, and found to be very successful. The details of the tests made and the results obtained are given in Table VII.

TABLE VII

Statement of tannin tests made and the results obtained

Year	Total No. of tests made	No. of positive tests	No. of fields selected for manuring	Dose of sulphate of amm. md. per acre	Yield of *kapas* md. per acre		Increase
					Control	Manured	
1939	45	22	15	2	7·21	11·21	4·0
1940	265	123	55	2	10·48	12·66	2·18
1941	326	173	22	2	11·38	14·24	2·86

The results show that it would be profitable to apply sulphate of ammonia to the fields that give the test. In 1940 the magnitude of increase was relatively small as majority of fields selected for the test and subsequent manuring had already turned very pale so that it was too late to correct the internal disorder in the plants at such an advanced stage of nitrogen starvation. Fields selected for the test should be light green and should possess perfect stand in order to obtain best results from manuring. It may be mentioned that this test for manuring cotton has only been found successful in the Punjab. It is possible that similar results may not be obtained in other cotton tracts.

Conclusions

The problem of manuring cotton centres round the availability and the application of nitrogenous manures as phosphorus and potash have not generally been found to be limiting. Nevertheless the problem did not prove to be quite simple as the magnitude of response to nitrogen was found to be governed by a multitude of factors of which the soil was most important. While the *desi* variety could profitably be manured on a wide range of soil conditions, the American cottons responded only on light sandy soils free from subsoil *kalar*. On sandy loam fields with saline or alkaline subsoil the response was either low or nil. The increase in yield was of a medium order when light sandy lands had also some alkali concentration in the subsoil. Where the different soil conditions were found intermixed, the relative proportion of each determined the ultimate gain from the application of nitrogen. This finding explains at least in part the cause of wide variations in the results obtained with nitrogenous fertilizers and the difficulty experienced in making a general recommendation for cotton manuring.

The original nitrogen status of the soil is no less important, provided other soil factors are favourable. The increase in any crop produced by a unit increment of a deficient factor is proportional to the decrement of that factor from the maximum (Mitsherlich). Practices such as fallowing, restorative rotations providing legumes, green manuring and the use of other organic manures that raise the nitrogen level of the soil make it less and less responsive to the application of nitrogen.

A simple and expeditious device designated as the 'tannin test' has been evolved and described, the use of which enables one to detect fields suffering from nitrogen deficiency without recourse to soil analysis. This biochemical test is applied to the aqueous extract of the leaf just before the onset of flowering. Once the positive test is obtained, sulphate of ammonia can be applied at the rate of 2-3 md. per acre.

The influence of sowing date, spacing, and variety in modifying the response to nitrogen on light sandy soils cannot be ignored. May-sowings possess greater potentiality for increase in yield through manuring than the June-sowings. The usefulness of nitrogen falls off as the sowing date advances so much so that the June-end sowings derive the least benefit. The manurial response to late sowings can, however, be greatly improved by close spacing.

The different strains of cotton were found to respond to nitrogen in the order of their yielding capacity, i.e. greater the yield, greater the response and vice versa.

The behaviour of the organic manures in relation to the soil conditions was similar to that of ammonium sulphate, and from one year's trial *toria* cake appears to be a good substitute for this inorganic fertilizer.

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COMPARATIVE STUDIES ON INDIAN SOILS

I. REGIONAL AND ENVIRONMENTAL FACTORS ASSOCIATED WITH INDIAN SOILS

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THE work on this subject is reported in a series of topics. It represents the coordinated team work in the Chemical Section of the Imperial Agricultural Research Institute under the direction of the senior author and is designed to form the basis for the interpretation of Indian soils in the light of modern developments in soil science both in its theoretical and practical aspects. To this end comparative data are obtained on the relevant physico-chemical and bio-chemical properties of soils in relation to colour, climate, geographic distribution and life in the soil.—B.V.N.

OBJECT AND SCOPE OF THE ENQUIRY

FARMING, whether intensive or extensive, requires knowledge of soil factors for handling soil questions. As knowledge of soils increases, more rational and more economic methods become available for the reclamation and utilization of new and derelict lands; the practice of growing crops unsuited to any particular soil can be prevented; better use can be made of manures, fertilizers and irrigation waters; there will be improvement in farming whose welfare is linked up not only with the quantitative and qualitative aspects of production but also with economic conditions in respect of costs and prices.

In India, we have stabilized soils and long established agricultural systems and practices many of which are scientifically and economically sound. The practical knowledge that accumulated through long experience and tradition was, till the beginning of the present century, the sole factor that governed the distribution and management of crop and animal husbandry in the different regions of the country.

A forward move became possible with the establishment of agricultural research institutes 40 years ago, and the scientific study of Indian soils has been in progress since then. In those days the terms 'pedology' and 'soil science' were not known. The scientific ideas on soils were based largely on one or the other of two view points. One view was largely influenced by Liebig's mineral theory of plant nutrition, and looked upon soil principally as a chemical nutrient medium for crop growth; the other view held the soil as the surface modification of the geological formation. The former view prevailed with the agricultural scientists. Soil studies began, therefore, with the more obvious problems of soil fertility in terms of sufficiency and deficiency of fertilizer constituents and studies on soils were concerned principally with the chemical, physical and micro-biological properties of surface and subsoils. On the basis of these studies four major types of soils have been distinguished, namely the Indo-Gangetic alluvium, the black or *regur* soils, red soils and laterite soils. Each of these major types has its sub-types.

During the last two or three decades, the second view gained ground. Its ideas are similar to those of geology in the sense that they deal with the evolution of soils. Under the new concept, the soil is recognized as a dynamic body subject to perpetual changes and the future of the soil can be visualized from a knowledge of its past evolutionary changes. Originated by Glinka in Russia, tested and modified by Marbut for conditions obtaining in U.S.A. and by Ramann in Germany, the new concept rapidly gained ground and influenced soil research and thought in other parts of the world. The substance of the new concept is that the soil from the surface down to the parent rock below is considered as a natural body made up of parts which have grown or evolved together under the influence of the prevailing environment. There are forces at work making the soil and its body which is something different from transported or sedimented or deposited material. Prominence is given to the study of soil dynamics and regard is paid to the descriptive metamorphism of the soil profile, to understand the processes of changes concerned in the developmental history and morphology of the soil profile or section.

These developments which are very suggestive attracted attention in this country and influenced soil research in its scientific and applied aspects, and induced us to apply the methods in the study of our soils. Detailed studies are made on soil profiles in relation to the chemistry, physics and micro-biology concerned in the development of

profiles, horizons and in their structure, colour and other characteristics, and a large volume of data has accumulated. The time has come for the systematization and assimilation of the available data into farming practices and to fit our soils into the world scheme of soil classification and terminology.

An important feature of modern soil science is that it does not now speak of soil in terms of wheat soil, paddy soil, cotton soil and so on. Soils are classified and named on the basis of the distinguishing characteristics of the soil profiles which have developed under natural conditions. The scientific point of view cannot, however, be separated from the agricultural point of view. Much of the significance is lost if the new system is not related to the practical aspects of agriculture. Indian soils are largely under relatively dry tropical and sub-tropical conditions. There is in vogue the colour classification which, though empirical, signifies correctly major characteristics and agricultural practice associated with the soils. The farmers recognize different kinds of soils on the basis of differences in the management of soils and their productivity and their agricultural practices are governed largely by these considerations. The general and local names given by the farmers to their soils are descriptive and tell with a reasonable degree of precision the agricultural properties of the soil. It is, therefore, important to ascertain to what extent soils differentiated on the basis of their workability and productivity correspond to types classified according to modern soil science. In other words, we should endeavour to correlate the new system with actual farming in the country, in order that the farmer and the soil scientist in India may speak common soil-language and that the results of research may be utilized for the solution of practical problems. Also, it is desirable to correlate the local terminology with the international nomenclature, for the necessary understanding by soil workers in and outside India.

What has just now been said becomes obvious when it is stated that facts derived from laboratory studies and field experience have revealed that the principle and practices developed elsewhere have been found in many cases unsuitable for application to our soils without substantial modifications. For example, heavy clays which in other countries would be classed as unfit for crop growth are known to yield good crops in India. The nitrogen and phosphate contents of many Indian soils which grow good crops are of an order which would be declared as being deficient in these constituents for the soils of the temperate regions. The nitrogen recuperation powers of Indian soils are greater than those of the temperate regions. Frequent and deep cultivation with or without soil inversion is not always and every where followed with economic results and in some cases the results have even been injurious.

It is important, therefore, in order to distinguish between the processes and their intensities in soil and plant growth in temperate and tropical conditions, the available data should be coordinated in order to have more precise and comparative information for the interpretation of soils and their performances and to ascertain how far Indian soils fit into the world scheme of soil classification and terminology. The available data of the past were obtained on different samples collected at different times and examined by different methods. Also the studies of the early days were made under the older concepts. It is, therefore, unsound to rely on the available data in comparative soil investigations for assessing the scope of recent developments in soil science either in the evolution of new principles and practices or in the modification of older ones. The first step then is to secure comparative analytical data by identical methods of collection of samples and their analysis.

The object of the study, therefore, is to obtain in the first instance, data on the characteristics of soils to ascertain relationships between them and between the horizons in individual profiles. The data will then form the basis for the interpretation of soils, and the effects of manures, fertilizers, irrigation and plant response. Such information will be found useful to students of soil science and to students of agronomy to whom more knowledge of our soils is a matter of increasing interest and importance.

To this end samples of soils, from virgin and cultivated areas from the localities where experiment stations exist in different parts of India, were collected by the members of the Section in the same year and in the same month. The places where experiment stations exist have been selected so that the crop data available at those places may be made use of in interpreting the soil data. Stress has been laid on the importance of uniformity in the description of the profiles, collection and preparation of soil samples which

were analysed by experienced analysts, employing approved and established methods of analysis.

The scope of the enquiry is limited, in the first instance, to the study of soils which have not been under cultivation, the changes which profiles undergo with variations in temperature and intermittent aridity, hydrostatic pressure and other variable conditions. These variables individually and jointly control the transformations in the regional soils. The scope of enquiry is, therefore, designed to secure comparative data on the nature, geological, physical and chemical composition, and properties arising under isothermal and isodynamic conditions and hydrostatic pressure (humidity).

SURFACE GEOLOGY AND PROFILE MORPHOLOGY

The soils of India like those of other countries may be divided into two broad divisions, namely drift and residual soils, majority being included in the first type. The alluvial soil mantle of northern India and of coastal plains and certain localized areas in peninsular India are mostly drift soils formed by deposition of alluvial and windborne debris, while a large part of peninsular India are residual soils and soils formed *in situ*. Indian soils, however, offer a distinct contrast to those of many other countries in that they are old, mature and do not show generally the pedogenic processes and the close relationship between the soil and its rocky substratum. The great majority of soils of northern India are of alluvial origin derived from the sedimentary rocks of the Himalayan range of mountains while those of the peninsular India, which represents the ancient table land are derived from the ancient and earliest formed gneisses and schists and the Deccan trap rocks.

The earliest investigations by Volclcker at first in the year 1893 and the later studies by Leather [1898] distinguished four major types of soils—the Indo-Gangetic alluvium, the black or *regur* soils, red soils lying on metamorphic rocks, and the so-called laterite soils. In addition, stretches of alluvium along the coasts and the mouths of the great rivers have been noted to occur. From his studies on the composition of these soils, Leather found the brown deltaic alluvium of the great rivers of Deccan and peninsular India bear no relation to the Indo-Gangetic alluvium and in addition observed that soil covering what is known as the Dharwar system of the Western Ghats or Sahyadri hills to be very much different from the red soils of the metamorphic rocks. Leather also observed that calcareous soils in the Indo-Gangetic alluvium contained nodular lime stones within a few feet below the surface and also intermixed throughout the soil mass.

The chemical composition of the soil is governed to a large extent by the original composition of the rocks from which the soils are derived and the nature of the chemical processes that have taken place during the formation of soils. The mode of rock formation has also a marked effect on the composition and properties of the resulting soils. A concise statement showing the surface geology of the localities from which the soils were collected is given in Appendix I.

In addition to its geological origin the soil is under the influence of major and minor effects of the phenomena of life in the soil, climate and seasons relative to the geographic coordinants measured and expressed in units of time, distance, temperature and hydrostatic pressure. Under the influence of climate geological differences are obliterated and soils of similar properties cover the most varied rock systems. The more extreme the climate the more generally will the climatic type of soil predominate. Examples are the black soils in India derived from different types of rocks. A mature soil is, therefore, the expression of geo-climatic and geo-biological forces which are jointly operating. The climatic environment impresses itself most on soils formed by the deposition of material transported great distances from the points of origin by the large number of great rivers traversing the country, and by high winds. For the reason that a large majority of soils in India are transported soils and for the reason that to a great extent the soils are in what may be characterized as dry tropics and sub-tropics with alternating periods of extreme aridity and humidity, a study on climatic basis is particularly apposite to Indian soils.

Climate is the nett result of atmospheric factors which make different regions and periods more or less suitable for supporting life. The two important climatic elements that influence soil processes are temperature and humidity. Water is a substance which is very largely concerned with the birth and development of soils and the life supported by the soils. Water takes a high place in two very important physical properties namely, specific heat and heat of evaporation.

Apart from the gross effects of flooding, transportation and leaching of soil material, under comparatively dry conditions water, in the shape of moisture, affects stabilization of temperature. In a dry atmosphere, a moist soil exposed to a rising atmospheric temperature exercises heat-dissipating capacity by virtue of its increasing vapour pressure. The result is that more and more heat is lost by evaporation and the soil acquires heat much more slowly than the surrounding atmosphere. Conversely, it cools down at a slower rate when the external temperature falls. Thus by its comparatively large capacity for heat, water in its various forms exercises control over what is called the climatic effect.

Several workers have from time to time endeavoured to correlate climatic factors with soils and soil processes and properties, and proposed various formulae for expressing the effect of climate (rainfall, humidity and temperature). The simplest and the most satisfactory formula is the one proposed by Meyer [1926] and known as Meyer's factor or humidity factor or N.S.Q. It is the ratio of precipitation or rainfall to the absolute saturation deficiency of the atmosphere. Jenny [1929] used this ratio for the soils of U.S.A. Prescott [1934] has used this in Australia. Recently, Hosking [1937] employed Meyer's factor in his studies on the relationship between the black earths of Australia and black soils of India. Raman and Satukopan [1935] characterized the climate of India by the annual rainfall minus the annual evaporation. Had there been data on effective rainfall (i.e. rainfall minus run off and evaporation) this value would have been more useful than Meyer's N.S.Q. The differentiation of India into broad climatic zones on the basis of N.S.Q. has been found to correspond with the natural adaptation of crops better than any other factor. The correspondence between climatic zonal classification of soils and the zonal adaptation of crops (rice, wheat and millets) is of value as a check and enables us to assess the bio-climatic character of the zone with reference to the type of farming, cultural practices and the type of products best adapted to it. This broad classification is of special value in bringing together under one coordinated system the major and minor groups of soils. In doing so, the object is to determine the characteristics of the soils and their profiles with reference to a zone and to the transition changes, if any, from one zone to another under the influence of factors operating in those zones and if possible and necessary to utilize variations, if any, as a basis for interpreting in a broad manner the response of soil types to the geo-climatic and geo-biological conditions obtaining in that zone.

The data for N.S.Q. have been calculated for India with the aid of meteorological data for India, details of which are given in Appendix II. The N.S.Q. divides India longitudinally into four broad divisions, beginning with arid in the extreme west and passing eastward through semi-arid and humid into perhumid or wet zone in the extreme east of the country. It will be noticed that these zones run at right angles to the latitude and this is largely because of the Himalayan mountain ranges on the north and of the effect of the sea on either side of the mountain ranges in the peninsular part of India.

The differerent climatic factors and their limits are shown in Table I.

TABLE I

	Arid	Semi-arid	Humid	Per-humid
Mean temperature °C.	24	26	25·7	24·4
Limits	22—27	24—29	24—28	19—26
Annual rainfall mm.	335	710	1265	2586
Limits	175—500	500—1040	916—1540	1870—3160
Humidity factor (N.S.Q.)	65	144	273	977
Limits	32—102	91—202	203—430	579—1726

The climatic factors, which are relatively of secondary significance in temperate countries acquire in India a major importance and exercise their influence in a higher degree, both in intensity and duration, than in Europe or Central Asia as can be seen from Tables II and III.

TABLE II

Temperature (°C.)

	Cold season (Jan. & Feb.)		Hot season (March to May)		Monsoon S. W. (June to September)		Receding Monsoon N. E. (October to December)	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Arid	21·4	7·0	33·9	18·3	38·0	26·0	28·0	11·5
Semi-arid	27·8	13·1	36·6	22·2	33·5	24·4	29·9	15·9
Humid	27·3	13·9	36·9	22·9	32·1	24·6	28·4	16·2
Per-humid	25·9	13·1	31·5	20·9	31·2	24·4	28·3	17·2

It will be seen that the arid region is under more extremes of temperature than either semi-arid or humid zones where high temperatures prevail almost throughout the year. Comparatively lower and more uniform temperatures are obtainable in the per-humid zone.

TABLE III

Rainfall

	Cold season (Jan. & Feb.)		Hot season (March to May)		Monsoon S. W. (June to September)		Receding Monsoon N. E. (October to December)	
	Rain-fall mm.	Per cent on total	Rain-fall mm.	Per cent on total	Rain-fall mm.	Per cent on total	Rain-fall mm.	Per cent on total
Arid	38·7	11·5	62·7	18·6	218·2	64·6	18·1	5·4
Semi-arid	23·4	3·3	51·8	7·3	523·5	73·9	110·1	15·5
Humid	35·1	2·8	76·3	6·0	1031·9	81·6	121·1	9·6
Per-humid	61·5	2·4	494·8	19·1	1841·8	71·2	188·0	7·3

The greatest precipitation takes place in the monsoon period preceded by smaller falls during the hot months. It is realized that the climatic differentiation of soil zones does not accurately locate the 'azonal' or 'intrazonal' soils. There is, however, the advantage that the soil type that may be expected under a given climatic regime and the agricultural behaviour of the soil may be known with a reasonable degree of certainty. It is interesting to note that a close correspondence exists between the geographic distribution of black, red and the so-called laterite soils and climatic zonation.

The description of the profiles examined is given in Appendix III. A feature of the field observations is the absence in the soils examined of profiles in the sense in which they are usually understood and described. In the drift soils or alluvial soils there is no clear demarcation of horizons or lines of contact and in many cases there is no close relationship between the soil and its rocky sub-stratum. The type of soil in the different regions is seen to a large extent decided by the climate of that area. For this reason profile samples were collected in foot depths, and where horizons could be differentiated, the samples were collected horizonwise.

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APPENDIX I

Profile No.	Station and popular general description of soil	N.S.Q.	Regional surface geology
1	Peshawar—Silty loam	69·2	Recent deposits Grey micaceous sandstones, shales, quartz, felspar and mica, Laki limestones of nummulitic origin. Salt ranges close by Kabul River.
2	Haripur (Hazara)—Silty loam	102·1	Sub-recent deposits—fluviatile, lacustrine and glacial alluvium. Bounded on 3 sides by Attock or Hazara slates which have dark coloured nummulitic limestones, some sandstone and trap. Depositions by the Dor River from the Tertiary and cretaceous systems. Also rhyolitic acid lavas.
3	Lahore—Loam	105·8	Recent deposits of River Ravi which rises in Jammu hills (tertiaries, Puranas, crystalline gneisses, etc.) and passes through meran shales and siwaliks, containing boulder-conglomerates, soft sandstones, red and purple shales.
7	Gurdaspur—Silty loam	188·0	Recent deposits. Doab of Ravi and Beas. Beas rises and passes through Himalayan granites and gneisses and siwaliks.
8	Kangra—Silty loam	..	Upper tertiary of the Sub-Himalayas; consists of boulder-conglomerates, sands and grit and massive grey sandstone with pale or drab shales (Siwaliks). Glaciers had extended within the district—great thickness of gravel and pebble beds over boulder-conglomerates are seen near Dalhousie.

APPENDIX I—*contd*

Profile No.	Station and popular general description of the soils	N.S.Q.	Regional surface geology
9	Lyallpur—Sandy Loam . .	60·6	Recent deposits; situated between rivers Ravi and Chenab. The latter rises from the slates and laterites and passes through shales and moraines. Coarse boulder-conglomerates occur at the points of emergence of the large rivers—the Ravi, Chenab and Jhelum and their principal tributaries. The intervening ground is occupied by massive beds of sand, grit and brown and red clays.
10	Mianwali—Sandy loam . .	67·1	Gondwanas, Upper Siwaliks and lower Miocene (Murree).
11	Sakrand—Silty loam . .	30·8	Recent deposits. Indus alluvium derived from shales and sandstones of gypseous and carbonaceous nature, massive nummulitic limestones of the Kirthar series, marine yellow limestones and shale (fossiliferous) of the Lower Miocene (Gaj series) and grey sandstones with conglomerates and brown and orange shales and clays.
12	Karachi—Sandy . . .	35·7	Recent deposits. Sandstones and fossiliferous marine limestones, marine yellow limestones and shales.
13	Mirpurkhas—Loam . .	32·0	Recent deposits. Indus alluvium.
18	Shahjahanpur—Loam . .	203·1	Recent deposits. Ganges valley chiefly the water worn debri of the outer Himalayas and the Siwaliks.
19	Padrauna—Sandy loam Low-land.	328·0	Alluvium of River Gandak—one of the oldest river course of India, which is now carrying down the detritus from a broad band of the siwaliks.
22	Ranchi—Clay loam Upland .	..	Bengal, gneiss.
24	Nagpur—Clay loam . .	225·0	Situated on the borderland of archean gneisses, deccan trap and lower Gondwanas occurring within a distance of about 2 miles.
25	Akola—Clay loam . . .	141·1	Lower trap of C.P. and Berar. The most common rock of Deccan trap is a normal augite-basalt of a greyish green tint-black or lighter shades are also seen.
26	Waraseoni—Loam . . .	275·2	Wain-Ganga basin. Granites and crystalline gneisses of Dharwarians and basic trappean intrusions. (Haematite-quartzite and Mn-epidotes. The yellow colour points to derivation from felspathic granites and laterisation is probably due to metasomatic surface replacement of slates and schists by Mn-bearing solution.)
27	Labhandi—Clay loam . .	237·5	Mahanadi alluvium. Lower Cuddapah or Bijawar series of Raipur-shales slates, quartzites and limestones.
28	Chandkhuri—Loam Mahanadi alluvium	246·3	
29	Kheri (Adhartal)—Clay loam .	304·6	Older Narbada alluvium. Slope is towards the Nerbada from the Vindhayans and an out crop of the Dharwarians of Central India.
30	Powarkhera—Clay loam . .	236·8	Older Narbada alluvium. Nerbada valley; the river traverses areas containing trap, Vindhayans, Archaeans and Gondwanas in different stages.
31	Indore—Clay loam . .	167·3	Southern face of a hillock in the trap area in Malwa; Malwa trap, the most prevalent constituent is normal augite basalt.
32	Kharna—Clay loam . .	149·9	Malwa trap.
33	Makrera—Sandy loam (Beawar)	104·8	Aravalli, Raialo and Delhi systems. Crystalline gneiss and granites of the Archaean systems.
34	Tabiji—Sandy loam (Ajmere) . .	110·2	Raialo and Delhi systems, as also Granites (Acid pegmatites) and syenites of the Archaean system. Composite gneisses from slates and phyllites by injection of granites. Archaean shales hornblende-schists and schistose conglomerate resting on the gneiss.
35	Jorhat—Sandy loam . .	1725·7	Recent deposits. Brahmaputra alluvium; the river passes over a zone of Bhabar deposits of stones, gravel and shingle for several miles before reaching Sibsagar district. A number of ridges runs more or less across the line of the valley down to the Mikir hills. These are sandy in character. A series of low hills are scattered in the greater part of the district, are red in colour and gneissic in character. The Jorhat ridge is deep, friable and Sandy.
36	Karimganj—Silty loam . .	1322·7	Recent deposits of Barak river, rising from Naga Hills. Its tributary Langai rises from Lushai Hills. Both rise from the Tertiaries of Eastern India mainly comprised of sandstones, shales, nummulitic limestones, argillaceous beds, etc. May also have the effect of Siwaliks containing thick coarse ferrugenous sandstones and sandy clays, etc.

APPENDIX I—*contd.*

Profile No.	Station and popular general description of soil	N.S.Q.	Regional surface geology
37	Sylhet—Sandy loam . .	1191·5	Recent deposits; Surma river, which rises from the Shillong plateau; the Jaintia Hills consisting of sandstones, shales and thin seams of coal and nummulitic limestones with local development of shales and sandstone.
38	Dacca—Loam . . .	579·2	Dacca stands on the bank of River Burhiganga. Recent deposits; Burhi Ganga river. The soil is of the same type as the older alluvium of the Brahmaputra and lower Ganges valleys.
39	Rangpur—Sandy loam . .	694·8	Recent alluvium; Rivers Teesta and Ghaghat, a branch orginally of the Teesta, now beheaded. The Teesta rises from the Dharwarian gneiss and crystallines of Darjeeling and Sikkim. The Teesta used to flow in the 18th century west of Rungpur, through Dinajpur, now it flows through the district in a S.E. direction and falls into the present Brahmaputra river.
40	Chinsura—Clay loam . .	430·1	Recent alluvium. River Bhagirathi, a branch of river Ganges. This tract is continuous with the alluvial area of the east coast and comprises the greater portion of the country to the westward of the Bhagirathi and probably the deposits from the Mor, Brahmani, Adjai and Damodar rivers which bring down materials from the hills of Manbhum, Singhbhum and Santhal Parganas.
43	Sirsi—Sandy loam	886·9	Gneiss and unclassified crystallines, and to the west a stretch of Dharwar series laterites.
48	Padegaon—Clay loam . .	137·0	Desh or dry tract of Poona in the Nira valley. The deposits of the Godavari and Kistna and their tributaries. In the upper reaches are chiefly composed of rolled agates and fragments of basalt derived from the Deccan trap. Accumulation of washings containing fine particles of soil from the Mawal tract (heavy rain) takes place. The prevalent rock of the Poona district is all trap in practically all the varieties.
49	Surat—Clay loam	202·2	Recent deposits; between the rivers Tapti and Narbada; south of Kirthar and Ranikot and West of Deccan trap area. Interstratified beds of gravel or conglomerate containing agate pebble derived from traps and limestone, frequently sandy, argillaceous or ferruginous and abounding in nummulites and other fossils. Some older alluvium of the upper basins of the two rivers, the Nerbada and the Tapti, are also brought down the upper basin covering a considerable depth beneath the levels of the river beds. Laterite beds occur interstratified with the lower Tertiaries near Surat.
50	Coimbatone—Sandy loam .	162·0	Granites and crystalline gneiss. Granitoid, hypersthene bearing rocks of the Charnockite series. Foliated among the gneiss are Nepheline-syanites and their pegmatites.
51	Taliparamba—Loam . .	762·4	Granites and crystalline gneiss of Malabar consisting principally of quartz, felspar, hornblende or mica and garnets and which weather readily into a ferruginous clay.
52	Koilpatti—Clay loam . .	154·4	Granites and crystalline gneiss. Kankar and calcareous rocks. (Gypseous). Cuddalore sandstones of Tinnevelly district consisting of highly ferruginous gritty and sandy beds, coloured yellow, brown red or purple and sometimes white or pale-coloured. Clays and shales are interstratified ocassionally.
54	Hagari—Clay loam . .	91·2	River Hagari. Granitoid gneisses and Dharwars. The massive gneisses are of two types—(1) Porphyritoid grey rough gneiss of quartz and pink orthoclase felspar and hornblende, and (2) Red granitoid gneiss of a close-grained aggregate of quartz and felspar.
55	Nandyal—Clay loam . .	127·3	Cuddapah and older paleozoic shales of Kundair group of the Karnul series (Nandyal shales), composed of purple calcareous shales and earthy limestones passing insensibly into compact crypto-crystalline, flaggy limestones (Koilkuntla band). Nandyal shales are soft and crumbling.
56	Samalkot—Loam . . .	223·0	Godavari Delta. Coastal alluvial deposits. Trap and Khondalites.

APPENDIX I—*concld*

Profile No.	Station and popular general description of soil	N.S.Q.	Regional surface geology
57	Anakapalle — Sandy loam Coastal alluvium	182·2	Granites, crystalline gneiss and khondalites. An extensive development of Bezwada gneiss of a dark brownish colour composed principally of lustrous red murchisonite felspar with abundantly scattered garnets. Graphitic schists are also found here and there. Contains some bands of crystalline limestones.
58	Berhampur — Sandy loam Coastal alluvium	301·5	Granites and crystalline gneiss. Charnockite gneiss of the nature of igneous plutonic rocks.
59	Pusa—Sandy loam	..	Recent deposits. Boor Gandak River. Alluvium of the Boor Gandak which rises from rocks composed of granites, gneisses and Dharwarians of the Himalayas and passes through a broad belt of the Siwalik foot hills and coastal Tertiary deposits.
60	Delhi—Sandy loam Jumna alluvium	123·6	Triassic-Delhi system of the Aravallis composed of ferruginous and lime quartzites, grits and schistose rocks intruded by large bodies of granite and amphibolites. The schistos rocks consist of biotite schists, phyllites and impure biotitic limestones.

APPENDIX II

Climatic factors

(Compiled from Annual summary of India Weather Review, 1938, Pt. A)

No.	Stations	Temperature				Vapour pressure mm.	Absolute saturation deficit mm.	Yearly rainfall mm.	Humidity per cent	Meyer's N.S.Q.	Lang's R.F.	Elevation in feet above mean sea-level
		Mean max. °F.	Mean min. °F.	Diurnal difference	Average °F.							
1	Peshawar	84·7	60·3	24·4	72·5	11·54	4·96	343·2	57	69·2	15·3	1,110
2	Haripur-Hazara	85·0	60·0	25·0	72·5	11·54	4·96	506·5	57	102·1	22·5	1,730
3	Lahore	89·6	60·6	29·0	75·1	12·40	4·71	498·4	62	105·8	20·9	732
4	Ferozepur	87·8	64·0	23·8	75·9	12·67	4·44	729·2	65	164·4	29·9	..
5	Kalashakaku	89·0	60·8	28·2	74·9	12·57	4·53	571·5	64	126·3	24·0	..
6	Gujranwalla	88·4	61·0	27·4	74·7	12·75	4·34	643·1	66	148·4	27·1	..
7	Gurdaspur	88·4	61·0	27·4	74·7	12·57	4·02	755·7	68	188·0	31·9	800
8	Kangra	75·0	58·0	17·0	66·5	10·54	2·85	1,869·4	73	656·0	97·4	3,000
9	Lyallpur	88·6	62·1	26·5	75·4	12·24	5·51	334·0	55	60·6	13·9	605
10	Mianwali	86·9	60·2	26·7	73·6	12·32	4·93	331·0	60	67·1	14·3	750
11	Sakrand	93·3	68·2	25·1	80·8	13·84	5·54	170·7	60	30·8	6·3	110
12	Karachi	88·0	68·0	20·0	78·0	15·32	5·36	191·5	65	35·7	7·5	49
13	Mirpurkhas	93·1	68·5	24·6	80·8	13·84	5·54	177·5	60	32·0	6·5	95
14	Aligarh	89·1	64·3	24·8	76·7	12·42	5·34	524·3	57	98·2	21·1	..
15	Cawnpore	89·9	66·4	23·5	78·2	14·45	4·91	912·4	66	185·7	35·5	..
16	Gorakhpur	87·7	66·7	21·0	77·2	16·26	4·07	1,275·0	75	313·6	50·8	..
17	Fyzabad	88·7	66·2	22·5	77·5	15·52	4·35	1,127·0	72	259·4	44·5	..
18	Shahjahanpur	89·1	65·3	23·8	77·2	14·55	4·51	916·2	69	203·1	36·5	475

APPENDIX II—*contd*

No.	Stations	Temperature				Vapour pressure mm.	Absolute saturation deficit mm.	Yearly rainfall mm.	Humidity per cent	Meyer's N.S.Q.	Lang's R.F.	Elevation in feet above mean sea-level
		Mean max. °F.	Mean min. °F.	Diurnal difference	Average °F.							
19	Padrauna	87·7	66·7	21·0	77·2	16·26	4·07	1,335·0	75	328·0	53·2	260
20	Orai	91·2	69·0	22·2	80·1	13·44	5·64	918·7	58	162·8	34·4	..
21	Sabour	86·3	65·6	20·7	76·0	16·87	3·71	1,218·0	78	328·1	49·9	..
22	Ranchi	84·2	65·5	18·7	74·9	13·44	4·57	1,455·7	66	318·5	61·3	2,150
23	Patna	87·3	68·6	18·7	78·0	16·66	4·67	1,233·0	72	264·2	48·2	183
24	Nagpur	92·0	68·8	23·2	80·4	13·49	5·53	1,244·0	59	225·0	46·2	1,025
25	Akola	93·2	67·4	26·8	80·3	12·83	5·64	796·3	56	141·1	29·7	930
26	Wara Seoni	87·6	64·6	23·0	76·1	12·60	4·91	1,352·0	61	275·2	55·2	600
27	Labhandi	90·2	67·5	22·7	78·9	14·33	5·44	1,292·1	62	237·5	49·5	..
28	Chandkhuri	90·2	67·5	22·7	78·9	14·33	5·44	1,339·8	62	246·3	51·3	..
29	Kheri-Adhartal	88·4	63·8	24·6	76·1	13·13	4·69	1,460·9	65	301·6	57·1	1,306
30	Poarkhera	90·3	65·5	24·8	77·9	12·78	5·24	1,240·0	59	236·8	48·6	980
31	Indore	88·2	63·9	24·3	76·1	13·23	5·03	841·2	52	167·3	34·3	1,823
32	Kharna	88·8	64·5	24·3	76·7	12·57	5·28	701·4	58	149·9	31·9	1,700
33	Makrera	88·5	65·2	23·3	76·8	12·52	4·76	498·6	62	104·8	20·0	1,700
34	Tabiji	88·5	65·2	23·3	76·8	12·52	4·76	524·5	62	110·2	21·1	1,500
35	Jorhat	81·3	65·7	15·6	73·5	17·53	1·40	2,416·0	92	1,725·7	104·6	250
36	Karimganj	86·1	67·5	18·6	76·8	18·39	2·39	3,160·2	87	1,322·2	120·9	100
37	Sylhet	86·1	67·5	18·6	76·8	18·29	2·38	2,835·8	87	1,191·5	113·9	90
38	Dacca	86·2	70·5	15·7	78·4	19·53	3·71	2,148·8	81	579·2	83·3	22
39	Rangpur	86·0	66·9	19·1	76·5	17·63	3·00	2,084·3	83	694·8	84·4	125
40	Chinsura	87·8	70·6	17·2	79·2	18·85	3·58	1,539·7	81	430·1	58·8	50
41	Dharwar	84·6	64·1	20·5	74·4	13·72	3·98	1,117·0	71	287·2	47·5	..
42	Sholapur	91·4	68·3	23·1	79·9	12·67	5·70	722·6	55	126·4	27·2	1,500
43	Sirsi	85·0	70·0	15·0	77·5	13·72	3·43	3,051·0	75	889·5	120·6	2,000
44	Nadiad	94·6	70·6	24·0	82·6	14·66	5·72	905·5	61	158·4	32·2	..
45	Bijapur	90·6	67·8	22·8	79·2	12·70	5·33	530·8	58	99·6	20·3	..
46	Belgaum	84·6	64·1	20·5	74·4	13·97	4·75	1,016·0	66	213·9	43·2	2,550
47	Kunta	86·1	72·7	13·4	76·4	19·18	3·07	3,048·0	84	993·2	123·4	..
48	Padegaon	90·6	67·8	22·8	79·2	13·72	4·80	657·6	65	137·0	25·1	1,000
49	Surat	91·5	69·9	21·6	80·7	17·14	5·14	1,041·0	70	202·4	38·4	36
50	Coimbatore	89·9	69·7	20·2	79·8	18·39	3·49	566·2	70	162·0	21·3	1,348
51	Taliparamba	87·7	74·4	13·3	81·1	20·45	4·09	3,118·2	80	762·4	114·2	600
52	Koilpatti	93·7	74·2	19·5	84·0	19·05	5·52	852·9	71	154·4	29·5	400
53	Aduturai	90·2	76·2	14·0	83·2	20·73	4·97	1,396·0	76	280·7	49·2	..
54	Hagari	93·3	70·9	22·4	82·1	14·63	5·71	521·0	61	91·2	18·7	1,400
55	Nandyal	93·8	71·2	22·6	82·5	16·20	5·19	660·7	68	127·3	23·5	960
56	Samalkot	89·3	75·0	14·3	82·2	20·24	4·45	992·9	78	223·0	35·6	30
57	Anakapalle	87·0	75·4	11·6	81·2	19·15	5·17	942·1	73	182·2	34·5	150
58	Berhampur	86·1	73·3	12·8	79·7	19·94	3·79	1,142·0	81	301·5	43·1	80
59	Pusa	87·1	66·5	20·6	76·8	16·10	5·67	1,178·6	71	207·9	47·3	164
60	Delhi	89·2	64·8	24·4	77·0	13·13	5·51	681·7	58	122·6	27·3	718

B

Appendix III

Profile descriptions, as seen in the field (virgin soil)

(Samples collected foot-wise)

Profile No.	Station	Depth of horizon	Characteristics
		(in.)	
1	Peshawar (Tarnab Farm)	0—48 48—60	Greyish pink soil Greyish pink soil but sandy
2	Haripur (Hazara)	0—12 12—60	Light brownish grey Greyish brown
3	Lahore	0—60	Light greyish brown
7	Gurdaspur	0—12 12—36 36—60	Dark greyish brown Brownish Brownish but more clayey
8	Kangra	0—24 24—36 36—48 48—60	Light blackish brown, bits of boulders Light brown, about 30 per cent boulders Light brown, about 25 per cent boulders fine sandy Light brown, about 25 per cent boulders and *kankar* coarse sandy Boulders of various sizes
9	Lyallpur	0—60	Light pinkish grey
10	Mianwali	0—36 36—48 48—60	Greyish pink Greyish pink *kankar* present Greyish pink few bits of *kankar*
11	Sakrand	0—12 12—48 48—60	Light grey Light grey more sandy Light grey more sandy feels salty
12	Karachi (Malir Farm)	0—36 36—60	Light brownish with pink tinge Dark brownish with red tinge
13	Mirpurkhas	0—36 36—48 48—60	Greyish brown Blackish and hard (compacted) Black and harder
18	Shahjahanpur	0—12 12—60	Dark brownish grey Light brown The first foot contains a very small quantity of *kankar* (0·1 per cent) which do not effervesce with dilute hydrochloric acid
19	Padrauna (Low land)	0—12 12—24 24—48 48—60	Dark blackish with brown tinge Light grey Light grey more sandy, lime *kankar* Light grey more sandy
22	Ranchi (Upland)	0—24 24—36 36—60	Dark red with brown tinge Less red Less red but more heavy
24	Nagpur (Morand)	0—12 12—24 24—60	Brownish black with white specks Brownish black a few pieces of lime *kankar* Brownish black, *kankar* increasing with depth
25	Akola (Morand).	0—60	Uniformly black with brown tinge. *Kankar* present throughout the profile, amount increasing with depth

APPENDIX III—*contd*

Profile No.	Station	Depth of horizon	Characteristics
		(in.)	
26	Wara Seoni (Sihar).	0—24	Slightly greyish yellow
		24—36	Murrum
		36—60	Soil mixed with stones
27	Labhandi (Kanahar).	0—36	Black with brown tinge, small *kankars*
		36—60	Black with brown tinge, *kankar* in greater amounts
28	Chandkhuri (Bhata).	0—5	Dark brownish red, *kankar*
		5—15	Red, more *kankar*
		16—28	Dark red, still more *kankar*
		28—60	Red *kankar* size larger
29	Kheri-Adhartal (Kabar).	0—24	Light black, brown tinge, lime *kankar*
		24—36	Grey, lime *kankar*
		36—60	Brownish, lime *kankar*
30	Powarkhera (Mariyar).	0—36	Greyish black with brown tinge, lime *kankar*
		36—60	Dark grey with brown tinge, *kankar* diminishing with depth
31	Indore	0—36	Light black, lime *kankar*
		36—60	Brown, *kankar* increasing with depth
32	Kharua (Kali).	0—36	Slightly brownish black, lime *kankars*
		36—48	Greyish, lime *kankars*
		48—60	Whitish, *kankar* increasing
33	Makrera	0—36	Brownish grey
		36—48	Murrum, limey
		48—60	Fine sand, limey
34	Tabiji	0—36	Brown
		36—48	Slightly black
		48—60	Sandy
35	Jorhat (High land).	0—12	Dark reddish brown with yellow tinge
		12—24	Greyish yellow
		24—36	Yellow
		36—60	Deep yellow
36	Karimganj	0—12	Slightly blackish brown, forms stiff clods on drying
		12—60	Yellowish brown, ferruginous nodules
37	Sylhet	0—12	Blackish brown
		12—60	Yellowish brown, gets more clayey with depth
38	Dacca	0—12	Light brown with yellow tinge
		12—60	Ochrey red, richer in colour with depth
39	Rangpur	0—12	Slightly brownish black
		12—24	Blackish brown
		24—48	Sand
		48—60	Highly sandy soil
40	Chinsura	0—12	Deep greyish brown, hard and gritty when dry
		12—60	Brown with blackish tinge
43	Sirsi	0—12	Dark greyish red
		12—24	Red, with decomposed rock
		24—36	Deeper red, with decomposed rock
		36—48	Red, gravels and undecomposed black iron nodules
		48—60	Red, disintegrated rock, more black iron

APPENDIX III—*concld*

Profile No.	Station	Depth of horizon	Characteristics
		(in,)	
48	Padegaon . . .	0—48	Black with slight pink tinge
		48—60	Greyish black, lime accumulation
49	Surat	0—12	Brownish black
		12—36	Black
		36—60	Blackish brown
50	Coimbatore . . .	0—24	Deep red black
		24—42	Deep red black, *kankar*
		42—54	Pale coloured, *kankar* smaller size
51	Taliparamba (Wet land). . .	0—12	Blackish red
		12—24	Light reddish black
		24—60	Reddish brown
52	Koilpatti (Typical gypseous). . . .	0—5	Mouse grey, loose granular
		5—12	Mouse grey, nodular, imbedded *kankar*
		12—24	Deep mouse-grey, prismatic, bigger *kankar* bits. A few gypsum particles
		24—36	Less deep mouse-grey, granular, both lime *kankar* and larger gypsum particles
		36—48	Mouse-grey, *kankar* size $\frac{1}{2}$ in. to $\frac{3}{4}$ in. diam., gypsum in flakes
		48—60	Dark olive grey, gypsum blocks, *kankar*
54	Hagari . . .	0—12	Greyish black
		12—24	Greyish black, *kankar* bits
		26—36	Greyish, slight foliation, some gypsum
		36—48	Greyish brown, some gypsum
		48—60	Brownish
55	Nandyal	0—60	Blackish grey, no marked difference between layers
56	Samalkot . . .	0—36	Light black with brownish tinge
		36 & below.	Water table
57	Anakapalle . . .	0—12	Dark greyish red
		12—48	Greyish red
		48—60	Light greyish red
58	Berhampur . . .	0—12	Greyish black
		12—24	Whitish grey
		24—36	Light brown
		36—48	Very light brown
		48—54	Whitish brown
		54 & below.	Red gravels
59	Pusa	0—12	Greyish brown
		12—60	Whitish brown interspersed with lime *kankar*
60	Delhi	0—12	Light brown
		12—24	Slightly darker brown. Compaction at 22 in. and below
		24—36	Dark brownish grey. More compacted
		36—48	Dark grey with slight brown tinge. Heavier and more compacted
		48—60	Light brownish grey. White streaks and white incrustated cavities at 55 in. Lime nodules at 58 in. Less compacted

COMPARATIVE STUDIES ON INDIAN SOILS

II. THE COMPOSITION OF CLAYS FROM SOIL PROFILES

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The complex alumino-silicates of the mineral part of the soil constitute is what is commonly known as clay or clay colloids or clay complex. The clay complex is the ultimate product of weathering and is derived from the rock minerals. The clay is the most reactive portion of the soil and by virtue of its powers of absorption and ionic exchange capacity it controls the chemical and physical properties of the soil besides holding all the important elements of plant nutrition. A chemical analysis of the whole soil can indicate only the gross composition of the weathered and unweathered materials of the soil and of the extent of the reserves of plant nutrients contained in the soil. Such an analysis, however, does not indicate chemical reactions and the trend of soil processes in the soil profile, as clearly as the analysis of the clay fractions does. The clay fractions of soils from the different horizons of the several profiles described in part I of this series of papers, were separated and analysed.

Separation of clays from soils

Attempts were at first made to separate the clay fractions by means of Sharple's Super-Centrifuge, but that proved time-consuming. The separations were, therefore, made by sedimentation method, as is done in the mechanical analysis of soils. Two years later, we noticed that Kelley, Dore *et al.* [1939] in California also employed the sedimentation method for their studies on the colloidal constituents of California soils. The following is the method employed by us for the separation of clay: The soils after rubbing with a wooden mallet and separation from gravel and *kankar*, etc. was passed through 2 mm. sieve. That which passed through the sieve was taken for the separation of clay. 500 c.c. of distilled water was added to every 25 gm. lots of soil and boiled for 15 minutes. After cooling the suspension was vigorously shaken by hand after adding 25 c.c. of ammonia (4 : 1) as a dispersing agent. This was then made up to 2,500 c.c. and transferred to a glass vessel of a size sufficient to give 10 cm. depth of supernatant suspension. At the end of 24 hours, the supernatant suspension of clay was siphoned off. Then the residue was rubbed with a rubber-tipped glass rod, made up with distilled water to a height of 10 cm., allowed to settle for 24 hours when the supernatant clay suspension was drawn off and added to the previous lot. This process was repeated till the supernatant liquid was almost free from suspended clay particles. Four or five successive pourings usually give a fairly clear supernatant liquid. These pourings were mixed and then boiled to coagulate the clay suspension. On settling of the clay the clear supernatant liquid containing any soluble salts was thrown away. After drying the creamy material first at 95-100°C. and then at 105°C., the clay samples were powdered and stored for analysis.

The following methods of analysis were adopted —2 gm. of clay, after determining hygroscopic moisture at 107-8°C., was subjected to digestion by Triacid mixture [Hardy, 1931 ; 1932]. This was then transferred to a beaker or a conical flask with 10 per cent HCl and digested on a bath for about four hours and filtered.

The residue was dried, ignited and weighed as sand. It was then transferred to a beaker, digested with 1 per cent NaOH for about an hour on a boiling water-bath with constant stirring, filtered and residue of quartz washed free of alkali with cold 10 per cent alcohol. Ignited and weighed. The difference between the sand and quartz gives the amount of soluble silicates.

The usual analytical procedures of the A.O.A.C. were adopted for the determination of alumina, iron oxide and lime. The filtrate from lime was evaporated down to dryness and ammonium salts were removed by ignition. The residue was digested with 10 per cent hydrochloric acid on a water bath for about half an hour and filtered. A convenient volume was made up of the filtrate and divided into two portions. In one portion the magnesium was determined as the pyrophosphate and the other portion was used for the determination of mixed chlorides of magnesium

potassium and sodium. The residue of triple chlorides was then taken up with hot water and potassium was determined by the Lindo-Gladding method. Sodium was obtained from the mixed chlorides after deducting the calculated amounts of magnesium and potassium obtained previously.

Analytical results are presented in Appendix.

Soil type and composition of clay

The analytical data on clays have been grouped according to climate into the four main zonal types of soils, namely arid, semi-arid, humid and per-humid and according to colour classification in vogue. Soils with calcium carbonate content of 10 per cent and over have been grouped separately as calcareous type of soils and separate from the major climatic or colour types but occurring within the major types.

Type—Arid soils. The average composition of the clays for the profile of the arid type of soils works out as shown in Table I.

TABLE I

Average composition of clay in the arid type of soil profile

Depth (in ft.).	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	49·70	12·01	37·69	9·41	21·80	2·34	2·39	4·03	4·22
1—2	49·93	10·07	39·86	10·47	22·56	1·93	2·42	3·89	4·32
2—3	50·65	11·06	39·59	10·29	22·38	1·73	2·16	3·26	3·80
3—4	50·96	12·04	38·92	10·08	21·76	1·80	2·44	3·33	4·31
4—5	51·43	14·62	36·81	10·44	20·90	1·81	2·35	3·60	4·41

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	15·20	0·628	0·059	0·214	*0·042*	0·058	0·043	0·068
1—2	18·14	*0·664*	*0·666*	*0·221*	0·034	0·060	0·042	0·070
2—3	20·46	0·659	0·065	0·220	0·031	0·054	0·035	0·061
3—4	24·86	0·648	0·063	0·213	0·032	0·061	0·036	0·070
4—5	24·01	0·613	0·066	0·205	0·032	0·058	0·038	0·071

There is a tendency towards a lowering in the amounts of combined silica, iron oxide and alumina in the topmost layer and an accumulation in the second layer. A gradual falling off of the values with depth is noticeable afterwards, except for a slight rise in value of iron oxide in the last depth. The highest content of lime, as would be expected under the climatic conditions, is found in the first depth remaining practically unchanged throughout in the lower depths. Same is true for potash, which is rather high due probably to the presence of undecomposed feldspars. Magnesia and soda are found to remain practically constant throughout the profile. Lime and soda are slightly in excess over magnesia and potash and the monovalent bases are present in higher proportions than the divalent bases indicating conditions of salinity. The analytical values as well as the clay content of the soil from different depths show slight increase of finer particles down the profile.

TABLE II

Derived and property values

Depth (in ft.)	Weathering per cent	Combined $\frac{SiO_2}{R_2O_3}$	Combined $\frac{SiO_2}{Fe_2O_3}$	Combined $\frac{SiO_2}{Al_2O_3}$	Combined $\frac{SiO_2}{Bases}$	$\frac{Al_2O_3}{Fe_2O_3}$	Saturation (Ex. bases) per cent	pH antimony electrode
0—1	75·8	2·31	10·74	2·95	3·09	3:65	96·1	7·35
1—2	80·0	2·33	10·50	3·03	3·40	3·50	94·8	7·33
2—3	78·7	2·34	10·53	3·03	4·27	3·47	98·0	7·23
3—4	76·7	2·37	10·62	3·08	3·67	3·47	96·3	7·26
4—5	72·0	2·30	10·25	3·06	3·45	3·50	98·5	7·31

Table II shows the constancy of composition of the clay minerals in all the depths, the only exception being the base contents which have accumulated at the surface probably by capillary rise as is indicated by the gradual increase in SiO_2/ base values. The clay of the last depth is more quartzose than those from the upper layers. Under the high prevailing temperature of 24·2°C. and a scanty and precarious rainfall of 11·4 in. per annum only a moderate degree of disintegration and a high accumulation of salts has taken place. The SiO_2/Al_2O_3 ratio of 3·03 shows that the colloid complex has probably a constitution intermediate between kaolinite and pyrophyllite, almost as a constant composition

mixture. The Al_2O_3/Fe_2O_3 ratio down the profiles is constant.

The arid type of soils have a pink, greyish pink or brownish pink colour due probably to the syenitic rocks in these regions. The average composition of clays of these profiles is given in Table III.

Table III

Average composition of clay in the profiles of pink coloured soils

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	49·77	11·27	38·50	10·87	21·75	1·81	2·20	3·43	3·46
1—2	50·01	11·19	38·82	10·63	24·01	1·30	2·02	3·51	3·28
2—3	50·17	12·22	37·95	10·06	24·24	1·33	1·68	3·28	2·74
3—4	49·20	12·31	36·89	10·05	23·81	2·61	1·83	3·03	2·77
4—5	49·18	14·99	34·19	9·46	23·07	3·30	1·90	2·93	3·22

The average sesquioxide ratios for the surface soils in the two types of classification are as below:

	Combined SiO_2/R_2O_3	Combined SiO_2/Al_2O_3
Arid type . .	$2{\cdot}31 \pm 0{\cdot}18$	$2{\cdot}95 \pm 0{\cdot}22$
Pinkish type . .	$2{\cdot}13 \pm 0{\cdot}58$	$2{\cdot}81 \pm 0{\cdot}57$

Type—Semi-arid soils. The detailed analytical data for the clays of the semi-arid type of soil profiles are given in statement in the appendix. The average composition is given in Table IV.

Table IV

Average composition of clays—semi-arid type of profile

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	50·96	7·16	43·80	11·31	22·01	2·24	2·12	1·91	3·17
1—2	51·37	6·85	44·52	11·64	23·10	2·00	2·10	2·02	3·15
2—3	50·31	6·30	44·01	11·31	23·20	2·02	1·96	1·91	3·20
3—4	50·33	6·03	44·30	11·33	22·70	2·71	1·90	1·84	3·35
4—5	49·09	7·35	41·74	11·04	21·41	3·81	1·98	1·92	3·59

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	36·85	0·729	0·071	0·216	0·040	0·053	0·020	0·051
1—2	40·42	*0·741*	*0·073*	0·227	0·036	0·052	0·021	0·051
2—3	43·40	0·735	0·071	*0·228*	0·036	0·049	0·019	0·052
3—4	41·87	0·741	0·071	0·223	*0·049*	0·047	0·019	0·054
4—5	40·33	0·695	0·069	0·211	0·068	0·049	0·020	0·058

It will be noticed from Table IV that as in the case of arid type soils, the constituents in the top layer are less than those in the next one below. The composition of the colloidal complex in the second, third and fourth layers has practically the same values. These three depths might thus be considered to be one horizon of the profile and with an average composition which works out as follows: 1-4 ft., 40·90, 0·739, 0·072, 0·226, 0·040, 0·049, 0·020, 0·052 and may thus be termed the illuvial layer. The fourth and fifth depths show the characteristic process of Marbut's Pedocal formation, where the calcium is converted to calcium carbonate and is then deposited as such at that depth. Calcium is solubilized as bicarbonate by carbon dioxide from organic decomposition, and its percolation to greater depths is not allowed by the low rainfall (27·8 in.) of this region and hence a deposit is formed at a depth to which the rain waters penetrate. Calcium-bearing materials can also rise from lower depths in the capillary water due to very high prevailing temperature (26·1°C.) of this region and are precipitated in the zone of calcification.

As in the case of arid soils lime plus soda is in excess over magnesia plus potash but divalent bases are in excess over the monovalent bases.

The major constituents are present in higher amounts in the semi-arid type of soils than in the arid type showing a greater degree of decomposition. The bases are present in lower amounts owing to a higher precipitation. CaO increases with depth here against a decrease in the arid type. Na_2O also shows a slight increase with depth, while magnesia shows decrease. K_2O is practically constant possibly as undecomposed feldspar. Except in the case of CaO the variations found are very small indeed and the colloids developed in this series show a singular uniformity

of composition. The relatively high values for MgO, Na_2O and K_2O indicate either the presence of minerals resistant to hydrolysis or that the colloid complex has a very strong affinity for these bases. A tendency towards increase in the clay colloids is shown here also (Table V) as in the case of arid soils.

TABLE V

Derived and property values

Depth (in ft.)	Weathering per cent	Combined SiO_2/R_2O_3	Combined SiO_2/Fe_2O_3	Combined SiO_2/Al_2O_3	Combined SiO_2/bases	Al_2O_3/Fe_2O_3	Saturation (Ex. bases) per cent	*p*H (Sb.)
0—1	86·0	2·53	10·65	3·40	5·34	3·18	96·8	7·72
1—2	86·8	2·50	10·70	3·31	5·54	3·26	95·3	7·63
2—3	87·6	2·51	10·88	3·29	5·28	3·35	95·0	7·57
3—4	87·9	2·56	10·92	3·37	5·09	3·25	96·3	7·19
4—5	84·8	2·53	10·58	3·37	4·27	3·15	96·3	7·76

Most of the above ratios for clays of this series are higher than those of the arid series excepting for a lower ratio Al_2O_3/Fe_2O_3 indicating the presence of a proportionately higher amount of iron oxide in the complex than alumina. Accumulation of calcium carbonate is reflected in the lower SiO_2/base ratios in the fourth and fifth layers. A loss of SiO_2 and Fe_2O_3 is indicated by the ratios SiO_2/R_2O_3 and SiO_2/Fe_2O_3 and points to the trend of the weathering processes. The small variations in the SiO_2/R_2O_3 values, when considered by themselves, show a constancy of composition of the major constituents throughout the profile, but the SiO_2/Fe_2O_3 and SiO_2/Al_2O_3 ratios show that there is an accumulation of Al_2O_3 with depth up to the third foot depth and then falls away and the ratio becomes constant; whereas Fe_2O_3 leaves the complex up to the fourth foot depth and is showing accumulation in the last or fifth foot depth indicating downward movement. The clay of the fifth foot is found to be more quartzose than the preceding layers, as was found with arid soils.

The mean value of 3·35 for SiO_2/Al_2O_3 suggests that the colloidal complex is composed of either (i) a mixture of kaolinite, Al_2O_3, 2 SiO_2, 2 H_2O and montmorillonite Al_2O_3, 4 SiO_2, H_2O, nH_2O the latter being in excess, or (ii) a mixture of Biedellite, Al_2O_3, 3 SiO_2, H_2O, nH_2O and montmorillonite, the former being in excess.

Type—Humid soils. The detailed analytical data for clays of the humid type of soil profiles are given in the statement in appendix. The average profile clay composition is given in Table VI.

TABLE VI

Average compositions of clays—humid type of profile

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	50·17	9·26	40·91	11·99	24·17	1·15	1·12	2·35	1·89
1—2	48·77	6·39	42·38	11·98	26·83	1·16	1·08	2·30	2·07
2—3	48·83	6·11	42·72	12·02	26·58	1·00	1·04	2·48	2·32
3—4	48·64	6·10	42·54	12·52	26·45	1·14	1·22	2·12	2·05
4—5	49·47	7·65	41·82	12·33	25·39	1·21	1·26	2·03	2·33

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	37·75	0·681	0·075	0·236	0·021	0·028	0·025	0·030
1—2	44·67	0·705	0·075	*0·263*	0·021	0·027	0·025	0·034
2—3	45·07	*0·711*	0·075	0·261	0·018	0·026	0·026	0·034
3—4	42·70	0·708	*0·078*	0·260	0·020	0·030	0·023	0·033
4—5	43·72	0·697	0·077	0·249	0·022	0·031	0·022	0·037

The table of molecular values shows the remarkable constancy in composition of the clay colloids of the second, third and fourth depths, the only departure being a very slight increase in the Fe_2O_3 and MgO content in the fourth depth suggesting their derivation from a common source or similar reactions. If the three depths are considered to be parts of the same horizon the following figures will indicate the analytical values for the clay of that horizon: 1-4 ft., 44·15, 0·708, 0·076, 0·261, 0·020, 0·028, 0·025, 0·034, showing an accumulation of silica, alumina and iron oxide in this horizon, the former two extensively. The bases show no change from their contents of the surface soil with the exception of a slight accumulation of soda. The clay content is also higher. A high degree of translocation of the fine colloids to these depths is indicated. The lower values for clay

silica, and sesquioxides in the first depth point to their eluviation to lower depths owing to heavier rainfall in this region. The base content is much lower, $CaO + Na_2O$ is balanced by $MgO + K_2O$ in all the depths. $MgO + Na_2O$ is in excess over $CaO + Na_2O$ (pointing to a micaceous clay) and the value increases with depth. R_2O is slightly predominating over RO.

TABLE VII

Derived and property values

Depth (in ft.)	Weathering per cent	Combined SiO_2/R_2O_3	Combined SiO_2/Fe_2O_3	Combined SiO_2/Al_2O_3	Combined SiO_2/bases	Al_2O_3/Fe_2O_3	Saturation (Ex. bases) per cent	pH (Sb.)
0—1	81·8	2·20	9·23	2·91	7·06	3·20	93·4	6·84
1—2	87·2	2·12	9·65	2·73	6·96	3·59	93·5	7·10
2—3	87·7	2·15	9·68	2·78	6·95	3·53	94·2	7·40
3—4	87·6	2·14	9·28	2·80	7·14	3·29	94·1	7·36
4—5	85·3	2·16	9·31	2·84	6·64	3·37	96·6	7·38

The figures in Table VII show that more silica is solubilized and is present in depths 2, 3 and 4 than what was present in the surface layer. Translocation of sesquioxides has also taken place as shown by SiO_2/R_2O_3 values, the maximum accumulation of alumina being in second depth and of ferric oxide in the fourth depth. In the upper layers the mobility of Fe_2O_3 is more than that of Al_2O_3. The gradual increase of SiO_2/Al_2O_3 values shows that alumina is leaving the complex while SiO_2/Fe_2O_3 values in the lower depths show an accumulation of Fe_2O_3 probably in the form of free oxide.

The eluviation of finer colloids, silica and sesquioxides is due to a break down of the clay complex and products subsequently becoming more mobile show the process of typical tropical weathering.

The silica/base ratio is practically the same except in the last depth where it is somewhat high due to a slight accumulation, as well as to a leaching away of silica owing to a definitely higher amount of precipitation of 50 in. annual rainfall. The saturation of the clay with exchangeable bases is somewhat lowered owing to the partial hydrogenation of the clay due to hydrolysis under definitely humid and hot conditions. This is also reflected in the *p*H value the lowest 6·84 being shown by the surface layer. The value gradually rises to 7·40 in the third layer and remains alkaline without further change—this has probably a connection with the higher Na_2O content in the lower depths.

As in previous cases, the clay in the last depth is more quartzose than the previous three depths but less so than the surface layer where the action of decomposition is most intense.

The humid soils are developed under an average annual rainfall of 49·6 in. and a mean annual temperature of 25·7°C. The surface layer is silty clay and the lower layers are clay loam.

The average value of 2·81 for SiO_2/Al_2O_3 points to the colloid being a mixture of Kaolinite and Pyrophyllite (Al_2O_3, 4 SiO_2, 3 H_2O), the former predominating.

In the semi-arid and humid zones occur black, brown and red soils, derived from almost all types of rock systems. These are not always residues which have survived weathering processes but are also transported soils with adsorption complexes of iron oxides and silicates. Those produced from lime stones are naturally rich in lime content and are more alkaline in reaction, e.g. Surat soil developed from Nummulites and Tabiji soil derived from igneous lime stones. These soils contain a proportionately higher amount of silicic acid which is due to the removal of the bases of the alkali and alkaline earth metals. An enrichment in both Fe_2O_3 and Al_2O_3 is also noticed.

The black soils are produced from decomposition of basalts gneisses and granites mostly in the semi-arid region. These soils are highly siliceous and contain somewhat lower amounts of sesquioxides than the brown soils. The average composition of clay from black soil profile is given in Table VIII.

TABLE VIII

Average composition of clay—black soils

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	52·30	5·94	46·36	11·04	22·67	2·26	2·16	1·50	2·36
1—2	52·96	6·28	46·68	11·38	22·79	2·22	1·99	1·44	2·88
2—3	51·81	5·86	45·95	11·30	22·44	2·06	2·04	1·46	2·83
3—4	52·21	5·46	46·75	11·41	22·33	2·30	2·09	1·37	2·93
4—5	51·17	6·69	44·48	11·20	21·43	3·20	2·01	1·36	2·94

TABLE IX

Type—per-humid soils

Average composition of clays—per-humid type of profile

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	44·03	7·48	36·55	10·27	28·19	0·44	1·34	2·14	1·68
1—2	45·74	9·31	36·43	9·09	29·56	0·36	1·08	2·45	1·65
2—3	46·11	9·78	36·33	9·91	29·47	0·34	1·06	2·33	1·44
3—4	46·97	10·76	36·21	9·89	29·73	0·33	0·91	2·15	1·58
4—5	47·21	11·33	35·88	10·67	29·97	0·34	0·90	2·03	1·76

Average analytical values—molecular per cent

Depth (in ft.)	Per cent clay in soil	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
0—1	15·52	0·564	0·064	0·277	0·008	0·033	0·023	0·027
1—2	23·87	0·607	0·063	0·290	0·006	0·028	0·026	0·027
2—3	26·77	0·592	0·062	0·289	0·006	0·026	0·025	0·023
3—4	30·15	0·603	0·062	0·292	0·006	0·023	0·023	0·027
4—5	24·03	0·598	0·067	0·294	0·006	0·022	0·022	0·028

The most notable feature in Table IX is the constancy of composition of the colloid, specially in the depths 2, 3 and 4. Leaching away of silica with consequent accumulation of iron oxide and alumina is shown by both the first and the fifth layers. The figures for Al_2O_3, Fe_2O_3 and SiO_2 all show a downward movement of the colloidal complex. This is also shown by the finer fraction of the soil—the clay. All the bases, with the exception of CaO are present in moderately high amounts, probably due to the entry of these bases, at least some, into the clay lattice by the replacement of H^+ ions of the hydrogen clay produced under the moderately heavy average annual rainfall of 98 in. This appears to be the most important soil-forming process in this region.

All the bases show a higher accumulation in the upper layers than in the lower ones. R_2O preponderates over RO and MgO + K_2O and MgO + Na_2O are in higher amounts than CaO + Na_2O and CaO + K_2O respectively, pointing to the presence of micaceous bodies.

The highest amount of alumina is present in this type of soils, while both SiO_2 and Fe_2O_3 are present in much less amounts than in the humid or even in semi-arid type of soils. This shows the removal of these constituents from the complex under conditions of very high rainfall, 97·7 in. per annum and high average daily temperature of 24·4°C.

The leaching down of alumina without sufficient SiO_2 to the depths is conducive to the formation of kaolin beds.

TABLE X

Derived and property values

Depth (in ft.)	Weathering per cent	Combined SiO_2/R_2O_3	Combined SiO_2/Fe_2O_3	Combined SiO_2/Al_2O_3	Combined SiO_2/bases	Al_2O_3/Fe_2O_3	Saturation (Ex. bases) per cent	pH (Sb.)
0—1	83·3	1·66	9·20	2·04	7·88	4·51	57·1	5·21
1—2	81·6	1·73	10·18	2·11	8·96	4·87	47·2	5·04
2—3	78·7	1·67	10·30	2·03	8·81	4·99	45·3	5·01
3—4	79·5	1·69	11·00	2·06	10·07	5·31	48·1	5·01
4—5	77·8	1·64	10·50	2·01	9·40	5·08	49·3	5·06

The silica/sesquioxide and silica/alumina ratios show that the soil-forming process governing this region has brought about a definite decrease in these ratios. The SiO_2/Fe_2O_3 and Al_2O_3/Fe_2O_3 ratios show a slight degree of fractionation of the colloid. The figures for SiO_2/R_2O_3 and SiO_2/Al_2O_3 show that the soil-forming process has gone beyond the kaolinization stage and is proceeding towards the laterization process—the first stage of which is generally assumed to be kaolinization. The kaolinized product is first formed by silicate minerals undergoing hydrolysis, the alkaline solutions being removed away. Under conditions of high temperature, 24·4°C., and abundant moisture due to high rainfall, 97·7 in., this kaolin is further hydrolysed with separation and removal of silica to hydrated oxides of aluminium and iron. The figures for weathering show a distinct leaching away of soluble silica resulting into the complex getting more and more quartzose. The high degree of unsaturation of the exchange bases also point to the process of laterization. This state

of unsaturation is also reflected in the pH values showing quite definite acidity.

Sesquioxides are relatively high in proportion to silica but have not yet reached the extreme proportions characteristic of true laterites. The decreasing values for SiO_2/Al_2O_3 show an accumulation of Al_2O_3 in the different layers, the highest being in the last depth. Higher values for SiO_2/bases in the lower layers show effective removal of bases, and decreasing values for per cent weathering show removal of soluble silica from the colloid complex.

The somewhat higher degree of saturation of exchange bases in the surface layer is probably due to the comparatively high amount, 2 per cent on soil, of organic matter present. Highest content of organic matter is found with soils of this type.

Most of the red soils including the so-called laterite soils are formed in the humid and per-humid regions. Brown soils occur in the humid region also. Some black coloured soils also occur in these regions produced under swampy conditions. In the humid and per-humid regions where high temperatures also prevail, a vigorous hydrolysis of silica and sesquioxides takes place, and the resultant colloidal iron oxide complex is diffused throughout the soil and endow it with red colour. These soils are not necessarily laterites in which the silica is also leached out while in red soils silica accumulates. The average composition of clays from red and brown soils is shown in Table XI.

TABLE XI

Depth (in ft.)	Total SiO_2	Quartz	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
				Red soils					
0—1	40·58	6·54	34·04	12·72	29·59	0·46	0·95	1·49	1·13
1—2	40·80	3·26	37·54	12·65	32·74	0·26	0·94	1·68	1·38
2—3	41·69	4·47	37·22	12·92	31·94	0·27	0·84	1·90	1·76
3—4	42·46	4·89	37·57	12·79	32·62	0·25	0·76	1·65	1·69
4—5	43·25	5·29	37·96	12·81	30·35	0·27	0·73	1·46	2·14
				Brown and reddish brown soils					
0—1	48·60	9·94	38·66	10·93	23·81	1·26	1·42	2·77	3·0
1—2	47·98	8·46	39·52	11·35	25·84	1·10	1·44	3·00	2·65
2—3	48·07	7·83	40·24	11·18	26·24	1·13	1·33	2·81	2·95
3—4	48·70	8·80	39·90	11·26	25·57	1·20	1·31	2·56	3·04
4—5	48·50	10·06	38·44	12·00	25·10	1·23	1·38	2·81	3·32
				Calcareous soils					
0—1	45·84	13·58	32·26	9·67	19·39	5·46	3·65	3·52	4·16
1—2	48·26	15·75	32·51	9·28	18·70	6·69	2·59	3·74	3·39
2—3	46·76	15·37	21·39	9·14	17·69	8·43	2·84	3·65	3·29
3—4	46·40	16·12	30·28	8·40	15·49	10·05	2·60	4·13	3·57
4—5	48·93	18·15	30·78	8·19	16·90	9·03	2·04	3·71	4·14

The average silica-sesquioxide ratios for the surface soils are given in Table XII.

TABLE XII

—	Combined SiO_2/R_2O_3	Combined SiO_2/Al_2O_3
Arid zone soils	2·31 ± 0·18	2·95 ± 0·22
Semi-arid zone soils	2·58 ± 0·39	3·40 ± 0·48
Humid zone soils	2·20 ± 0·37	2·91 ± 0·55
Per-humid zone soils	1·66 ± 0·34	2·04 ± 0·38
Pink and grey soils	2·13 ± 0·58	2·81 ± 0·57
Black soils	2·59 ± 0·35	3·40 ± 0·44
Brown and red brown soils	2·12 ± 0·50	2·81 ± 0·84
Red soils	1·56 ± 0·18	1·97 ± 0·25
Calcareous soils	2·15 ± 0·25	2·86 ± 0·37

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APPENDIX

CLIMATIC CLASSIFICATION

I. Soils of arid region

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Quartz	Combined silica	Total silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Mirpurkhas		12·45	37·84	50·29	9·23	23·51	2·69	0·80	3·45	2·71
2. Mianwali		11·27	38·14	49·41	8·15	20·36	2·42	4·01	3·93	2·94
3. Lyallpur		12·11	38·67	50·78	10·07	21·23	1·52	1·60	3·65	7·72
4. Haripur (Hazara)		12·21	36·10	48·31	10·19	22·08	2·73	3·13	5·10	3·52
	1—2									
1. Mirpurkhas		9·47	40·19	49·66	10·32	25·87	2·35	0·28	3·55	3·11
2. Mianwali		13·32	39·71	53·03	7·61	21·32	2·38	4·41	3·18	3·28
3. Lyallpur		11·57	38·41	49·98	12·66	19·39	1·46	1·46	3·39	7·25
4. Haripur (Hazara)		5·91	41·12	47·03	11·30	22·67	1·53	3·54	5·45	3·65
	2—3									
1. Mirpurkhas		9·76	40·88	50·64	10·49	25·57	1·33	0·41	1·42	2·47
2. Mianwali		13·99	39·22	53·21	7·67	20·20	3·00	3·69	3·26	1·72
3. Lyallpur		13·10	37·78	50·88	11·80	20·16	1·27	1·12	3·44	7·14
4. Haripur (Hazara)		7·40	40·48	47·88	11·18	23·58	1·33	3·43	4·90	3·89
	3—4									
1. Mirpurkhas		12·58	39·20	51·78	9·82	25·82	1·41	0·37	3·30	2·36
2. Mianwali		12·04	38·96	51·00	7·46	18·78	3·35	4·77	2·32	2·07
3. Lyallpur		17·53	36·15	53·68	11·87	19·16	1·18	1·24	3·12	7·02
4. Haripur (Hazara)		5·99	41·39	47·38	11·16	23·26	1·26	3·38	4·59	4·88
	4—5									
1. Mirpurkhas		13·52	38·84	52·36	10·82	25·12	1·68	0·25	3·02	2·79
2. Mianwali		20·45	31·04	51·49	5·44	18·77	3·21	4·42	2·09	4·32
3. Lyallpur		18·60	36·03	54·63	13·72	15·85	1·21	1·42	2·91	6·89
4. Haripur (Hazara)		5·92	41·34	47·26	11·79	23·87	1·24	3·32	5·49	3·65

II. Soils of semi-arid region

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Hagari		53·08	3·36	49·72	10·40	22·02	2·75	0·37	0·83	3·76
2. Lahore		46·97	5·04	41·93	12·82	24·38	1·47	2·29	3·76	5·23
3. Tabiji		48·22	9·40	38·82	10·56	18·81	2·81	0·23	2·18	3·45
4. Makrera		53·06	20·06	33·00	10·44	18·65	1·86	3·78	3·17	2·89
5. Delhi		52·88	3·81	49·07	13·34	21·68	1·67	0·86	2·77	6·56
6. Nandyal		53·88	2·53	51·35	11·07	26·26	1·64	0·57	1·08	4·09
7. Padegaon		51·00	1·69	49·31	11·00	19·17	3·22	4·89	0·66	3·22
8. Kharua		51·00	8·03	42·97	8·70	20·09	4·09	3·46	2·18	1·65
9. Akola		53·53	8·10	45·43	11·52	20·66	1·94	3·42	1·20	3·95

II. Soils of semi-arid region—*contd*

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
10. Koilpatti . . .		55·24	5·45	49·79	7·79	22·08	2·28	4·71	0·92	2·86
11. Coimbatore . .		53·26	12·00	43·26	10·30	23·67	0·68	0·32	0·97	0·84
12. Indore . . .		55·14	12·28	42·86	10·09	23·02	2·43	3·18	3·59	1·80
13. Anakapalle . .		44·19	3·32	40·87	16·08	21·79	1·12	2·25	2·16	2·25
14. Gurdaspur . .		43·12	8·95	34·17	11·14	23·68	2·71	0·37	2·59	4·77
15. Surat . . .		47·84	3·42	44·42	14·45	24·21	2·87	1·12	0·66	0·17
	1—2									
1. Hagari . . .		50·68	3·36	47·32	11·81	25·44	4·73	0·40	1·24	5·32
2. Lahore . . .		47·82	5·07	42·75	13·24	24·87	1·07	2·10	3·40	4·05
3. Tabiji . . .		50·06	14·45	35·61	7·53	24·23	3·23	0·26	4·98	2·24
4. Makrera . . .		51·80	15·69	36·11	10·97	20·26	1·47	4·15	3·35	2·85
5. Delhi . . .		49·60	3·86	45·74	13·64	23·09	1·22	0·88	3·03	4·86
6. Nandyal . . .		52·38	3·54	48·84	11·63	26·19	1·68	0·65	1·14	4·75
7. Padegaon . . .		51·02	1·63	49·39	10·95	19·56	3·00	4·80	1·00	4·10
8. Kharua . . .		52·34	8·79	43·55	8·89	20·35	4·00	3·34	1·96	1·44
9. Akola . . .		53·44	8·22	45·20	12·20	22·08	1·44	2·24	1·08	2·61
10. Koilpatti . . .		56·39	8·26	48·13	7·71	21·08	2·09	4·60	0·97	3·20
11. Coimbatore . .		52·87	8·42	44·45	11·18	25·09	0·86	0·33	0·52	0·78
12. Indore . . .		59·95	10·02	49·93	9·94	21·37	2·38	2·69	2·09	1·55
13. Anakapalle . .		45·37	2·79	42·58	15·92	22·91	1·01	2·16	2·24	2·20
14. Gurdaspur . .		45·87	5·24	40·63	12·91	28·10	0·75	0·36	2·59	4·24
15. Surat . . .		50·95	3·41	47·54	16·15	21·86	1·08	1·34	0·65	3·00
	2—3									
1. Hagari . . .		50·69	3·35	47·34	8·66	24·52	2·69	0·34	0·97	5·59
2. Lahore . . .		47·91	5·49	42·42	11·27	27·72	0·95	0·71	4·95	3·45
3. Tabiji . . .		47·85	8·87	38·95	9·60	24·51	3·02	0·37	2·01	3·08
4. Makrera . . .		50·58	13·59	36·99	10·73	20·45	2·24	4·15	3·05	3·04
5. Delhi . . .		49·76	3·82	45·94	13·37	23·63	1·87	0·39	2·97	4·76
6. Nandyal . . .		51·50	2·80	48·70	11·13	25·90	1·35	0·90	1·02	4·29
7. Padegaon . . .		52·22	1·66	50·56	11·42	18·47	2·91	5·03	0·47	3·66
8. Kharua . . .		50·20	8·02	42·18	9·24	21·07	3·95	3·40	2·03	0·79
9. Akola . . .		53·41	7·33	46·08	13·08	21·27	1·63	2·79	1·81	3·28
10. Koilpatti . . .		55·17	8·73	46·44	6·80	20·38	3·17	4·21	0·94	3·08
11. Coimbatore . .		53·33	10·12	43·21	10·02	25·60	1·51	0·30	0·60	1·34
12. Indore . . .		50·85	9·09	41·76	10·70	20·64	2·06	3·17	2·07	1·97
13. Anakapalle . .		44·61	2·90	41·71	15·76	22·94	1·23	2·12	2·31	2·28
14. Gurdaspur . .		46·17	5·93	40·24	11·67	28·64	0·77	0·48	2·58	5·02
15. Surat . . .		50·39	2·73	47·66	16·16	22·22	0·94	1·08	0·80	2·36
	3—4									
1. Hagari . . .		50·17	3·34	46·83	10·23	22·93	2·64	0·45	1·30	7·86
2. Lahore . . .		49·42	6·98	42·44	12·18	26·16	0·85	0·71	4·16	4·16
3. Tabiji . . .		50·66	10·25	40·41	10·12	23·40	2·44	0·49	2·44	4·06
4. Makrera . . .		38·85	8·26	30·59	9·54	18·77	10·67	4·30	2·09	2·04
5. Delhi . . .		52·14	5·48	46·66	14·18	21·79	1·85	0·59	2·92	4·24

II. Soils of semi-arid region—*concld*

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	3—4									
6. Nandyal		53·23	2·64	50·59	11·08	25·43	1·32	0·49	0·89	5·16
7. Padegaon		52·21	1·69	50·52	11·42	17·85	2·93	4·37	0·71	2·82
8. Kharua		51·49	8·04	43·45	9·17	22·15	4·11	3·25	2·01	2·38
9. Akola		52·91	6·26	46·65	12·46	22·56	1·69	2·02	1·45	2·26
10. Koilpatti		54·01	6·06	47·95	6·52	20·10	4·28	4·87	0·97	2·63
11. Coimbatore		53·43	11·38	42·05	9·55	21·43	3·00	0·26	0·65	1·47
12. Indore		52·21	8·46	43·75	10·41	23·07	2·26	3·22	3·16	2·06
13. Anakapalle		47·04	2·40	44·64	14·63	23·44	1·27	2·10	1·64	2·57
14. Gurdaspur		46·69	6·08	40·61	12·65	28·18	0·72	0·37	2·39	4·70
15. Surat		50·47	3·16	47·31	15·82	23·29	0·80	0·93	0·89	1·91
	4—5									
1. Hagari		50·19	4·44	45·75	12·41	24·50	2·00	0·40	1·23	6·13
2. Lahore		48·19	5·95	42·24	10·84	27·60	1·18	1·15	3·83	3·54
3. Tabiji		52·07	18·99	33·08	9·68	19·25	3·42	0·29	3·01	5·73
4. Makrera		39·85	16·54	23·31	8·20	13·70	14·85	4·64	1·70	2·18
5. Delhi		51·71	5·86	45·85	13·49	21·36	2·98	0·48	2·69	4·22
6. Nandyal		53·06	4·77	48·29	10·94	26·96	1·40	0·33	0·83	4·30
7. Padegaon		37·98	4·04	33·94	7·89	12·95	10·31	2·67	0·72	4·45
8. Kharua		50·33	8·03	42·30	8·50	21·19	5·53	3·48	2·06	1·54
9. Akola		51·50	3·72	47·78	13·00	20·84	1·99	2·61	1·52	2·85
10. Koilpatti		54·23	5·16	49·07	6·10	19·66	4·44	4·91	1·00	3·09
11. Coimbatore			..	..	..	..	..	..	..	..
12. Indore		53·85	12·04	41·81	11·11	21·40	2·05	2·73	2·74	2·11
13. Anakapalle		47·05	2·34	44·71	14·98	22·78	1·45	2·21	1·73	2·64
14. Gurdaspur		46·37	7·76	38·61	12·44	26·83	0·75	0·47	2·70	5·25
15. Surat		50·87	3·31	47·56	14·93	20·79	1·05	1·40	1·16	2·24

III. Soils of humid region

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Shahjahanpur		54·19	22·42	31·77	10·97	19·70	0·92	2·34	4·32	2·06
2. Samalkot		50·89	2·71	48·18	11·10	24·06	0·97	0·55	2·60	2·48
3. Nagpur		50·03	5·01	45·02	13·81	24·00	1·29	0·36	1·15	1·53
4. Powarkhera		53·98	11·49	42·49	9·13	23·01	1·97	2·72	1·99	1·38
5. Labhandi		50·63	8·92	41·71	11·14	25·73	1·03	1·32	2·18	0·98
6. Chandkhuri		45·54	14·47	31·07	14·67	25·47	0·11	0·49	1·72	1·88
7. Wara Seoni		42·57	2·26	40·31	12·37	27·44	1·33	1·16	2·75	2·56
8. Berhampur		55·19	10·29	44·90	11·79	19·08	0·94	0·66	3·24	3·29
9. Kheri-Adhartal		51·99	7·26	44·73	13·47	23·46	1·72	0·60	1·18	1·38
10. Ranchi		47·04	9·51	37·53	11·63	28·67	1·37	1·34	2·21	0·98
11. Chinsura		49·90	7·56	42·34	11·86	25·29	1·04	0·74	2·51	2·26

III. Soils of humid region—*contd*

Station	Depth (in ft.).	Total silica	Quartz.	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Shahjahanpur	1—2	46·12	7·60	38·52	12·87	29·27	0·68	2·29	4·10	1·51
2. Samalkot		50·74	2·51	48·23	11·11	24·50	0·94	0·42	3·00	3·89
3. Nagpur		51·12	3·63	47·49	13·83	22·97	1·77	0·60	1·47	3·03
4. Powarkhera		56·23	16·10	40·13	8·87	22·77	2·03	2·31	1·67	0·74
5. Labhandi		52·01	9·98	42·03	10·62	26·89	1·43	1·52	2·27	1·86
6. Chandkhuri		40·98	5·02	35·96	15·69	29·64	0·23	0·59	2·17	2·99
7. Wara Seoni		41·94	1·40	40·54	13·16	29·17	1·03	1·28	2·45	2·41
8. Berhampur		51·40	5·74	45·66	10·46	24·65	0·77	0·58	2·74	2·33
9. Kheri-Adhartal		50·23	5·83	44·40	13·41	25·36	1·56	0·43	1·02	0·97
10. Ranchi		45·13	5·23	39·90	9·85	33·12	0·53	1·27	2·22	1·00
11. Chinsura		50·64	7·28	43·36	11·90	26·75	1·76	0·59	2·20	2·09
1. Shahjahanpur	2—3	44·42	5·58	38·84	12·98	31·26	0·50	2·37	6·26	..
2. Samalkot		50·63	2·46	48·17	11·83	25·89	0·85	0·33	2·98	3·56
3. Nagpur		48·95	2·23	46·72	13·94	23·11	1·59	0·36	1·45	2·33
4. Powarkhera		56·39	14·80	41·59	9·29	21·84	1·84	2·20	1·45	0·98
5. Labhandi		50·75	7·80	42·95	11·37	25·97	1·10	1·72	1·68	1·91
6. Chandkhuri		41·64	5·53	36·11	15·37	29·02	0·22	0·43	2·05	4·23
7. Wara Seoni		42·67	1·33	41·34	12·25	29·72	0·97	1·12	2·31	2·38
8. Berhampur		52·62	4·96	47·66	9·78	25·00	0·68	0·59	2·97	2·62
9. Kheri-Adhartal		51·20	7·06	44·14	13·40	23·94	1·81	0·61	1·49	2·06
10. Ranchi		47·72	9·25	38·47	10·09	30·95	0·37	1·15	2·53	1·03
11. Chinsura		50·06	6·18	43·88	11·97	25·64	1·10	2·61	2·06	2·11
1. Shahjahanpur	3—4	43·98	6·80	37·18	13·04	30·25	0·56	2·39	4·22	1·58
2. Samalkot		..	..	..	..	..	..	..	..	..
3. Nagpur		49·72	2·20	47·52	14·68	22·81	1·47	0·43	1·48	3·02
4. Powarkhera		54·80	11·09	42·81	10·12	22·11	2·09	2·60	1·42	1·43
5. Labhandi		50·35	5·67	44·68	15·53	24·39	1·39	1·90	1·54	2·33
6. Chandkhuri		42·81	5·89	36·92	16·46	31·22	0·20	0·37	1·47	4·28
7. Wara Seoni		42·71	1·81	40·90	11·84	30·08	0·92	1·10	2·68	2·45
8. Berhampur		50·72	3·54	47·18	10·06	26·22	0·91	0·65	2·86	1·93
9. Kheri-Adhartal		53·03	6·19	46·84	13·61	23·32	1·68	0·42	0·84	0·72
10. Ranchi		48·18	10·76	37·42	10·18	30·36	0·47	1·41	2·57	0·69
11. Chinsura		50·15	6·18	43·97	11·66	23·74	1·71	0·92	2·15	2·09
1. Shahjahanpur	4—5	45·30	8·63	36·67	12·59	29·31	0·54	2·52	4·42	2·34
2. Samalkot		..	..	..	..	..	..	..	..	..
3. Nagpur		49·64	2·98	46·66	15·43	22·44	2·01	0·38	1·51	2·81
4. Powarkhera		55·49	13·40	42·09	9·77	22·42	2·83	2·84	1·33	1·53
5. Labhandi		51·58	8·31	43·27	12·24	24·52	1·48	2·24	1·50	2·17
6. Chandkhuri		43·31	2·71	40·61	16·99	24·60	0·22	0·32	1·56	5·63
7. Wara Seoni		42·28	2·68	39·60	12·28	29·62	0·93	1·07	2·66	2·39
8. Berhampur		49·79	4·24	45·55	9·74	25·38	0·88	0·63	2·36	2·65
9. Kheri-Adhartal		55·65	11·65	44·00	13·16	22·64	1·55	0·41	0·87	1·28
10. Ranchi		51·25	14·97	36·28	9·25	28·05	0·60	1·28	1·95	0·84
11. Chinsura		50·39	6·93	43·46	11·81	24·89	1·05	0·90	2·14	1·69

IV SOILS OF PER-HUMID OR WET REGION

Station	Depth (in ft.)	Total silica	Quartz	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Dacca . . .	0—1	44·01	3·71	40·30	7·82	29·42	0·19	0·15	1·90	1·61
2. Sirsi . . .		35·21	1·31	33·90	14·93	29·30	0·15	0·94	1·44	1·35
3. Kangra . . .		46·44	7·21	39·23	10·74	25·86	1·38	0·12	2·25	3·89
4. Rangpur . . .		50·06	12·20	39·50	12·49	22·56	0·61	3·50	3·88	2·36
5. Taliparamba . .		34·53	0·87	33·66	9·65	34·90	0·22	1·01	0·58	0·30
6. Karimganj . . .		44·55	4·25	40·30	9·80	30·09	0·46	2·81	3·25	1·58
7. Sylhet . . .		40·50	4·25	36·25	8·61	30·00	0·24	1·43	2·16	1·24
8. Jorhat . . .		55·27	26·05	29·22	8·11	23·39	0·27	0·79	1·66	1·14
1. Dacca . . .	1—2	45·51	2·33	43·18	8·07	32·08	0·12	0·32	1·70	1·66
2. Sirsi . . .		38·42	1·92	36·50	14·91	31·35	0·16	1·12	1·57	1·25
3. Kangra . . .		47·96	9·18	38·78	10·74	25·29	1·29	0·23	2·30	3·67
4. Rangpur . . .		50·50	23·83	26·67	8·90	23·00	0·30	1·29	5·78	3·11
5. Taliparamba . .		38·68	0·87	37·81	10·14	36·86	0·13	0·78	0·76	0·27
6. Karimganj . . .		45·13	4·35	40·78	10·25	30·10	0·46	2·53	3·10	1·84
7. Sylhet . . .		44·50	4·04	40·46	7·07	34·85	0·18	1·55	2·99	0·24
8. Jorhat . . .		55·27	27·98	27·29	9·82	22·96	0·22	0·81	1·40	1·14
1. Dacca . . .	2—3	45·88	2·47	43·41	7·07	32·44	0·10	0·16	2·07	1·36
2. Sirsi . . .		38·45	2·24	36·21	15·51	30·59	0·18	1·11	1·70	1·36
3. Kangra . . .		49·91	9·84	40·07	10·44	25·28	1·12	0·11	2·24	3·77
4. Rangpur . . .		51·70	31·80	18·26	8·80	22·10	0·32	1·74	4·71	0·86
5. Taliparamba . .		38·95	0·85	38·10	10·70	37·18	0·32	0·66	1·33	0·42
6. Karimganj . . .		43·83	3·81	40·02	9·51	29·46	0·43	2·47	3·02	2·05
7. Sylhet . . .		48·72	4·19	44·53	6·65	33·59	0·10	1·57	2·15	0·78
8. Jorhat . . .		53·09	23·03	30·06	10·61	25·14	0·15	0·63	1·45	0·93
1. Dacca . . .	3—4	47·71	2·55	45·16	7·18	32·15	0·08	0·21	2·10	1·45
2. Sirsi . . .		38·05	1·76	36·29	15·12	31·78	0·19	0·98	1·57	1·28
3. Kangra . . .		49·06	11·11	37·95	10·79	26·00	1·12	0·20	2·15	4·03
4. Rangpur . . .		55·95	36·71	19·24	8·63	22·72	0·38	1·64	4·11	1·20
5. Taliparamba . .		40·79	1·15	39·64	9·41	37·13	0·14	0·27	0·98	0·50
6. Karimganj . . .		43·98	3·72	40·26	10·88	29·56	0·45	2·40	2·38	1·70
7. Sylhet . . .		46·31	2·92	43·39	5·15	34·97	0·10	0·97	2·55	1·36
8. Jorhat . . .		53·92	26·16	27·76	11·93	23·51	0·20	0·60	1·34	1·08
1. Dacca . . .	4—5	49·86	3·10	46·76	8·20	32·80	0·11	0·29	2·01	1·50
2. Sirsi . . .		37·73	2·16	35·57	15·51	31·78	0·14	0·95	1·39	1·32
3. Kangra . . .		50·75	14·61	36·14	10·70	27·04	1·05	0·50	2·11	3·86
4. Rangpur . . .		55·57	36·44	19·73	8·72	24·11	0·57	1·71	3·92	1·82
5. Taliparamba . .		40·71	1·33	39·38	9·49	36·95	0·10	0·36	0·92	0·75
6. Karimganj . . .		45·95	4·34	41·61	9·43	30·55	0·43	1·68	2·38	2·31
7. Sylhet . . .		48·10	3·51	44·59	5·54	34·54	0·07	1·07	2·26	1·41
8. Jorhat . . .		48·37	25·13	23·24	17·77	21·95	0·28	0·64	1·28	1·08

CALCAREOUS SOILS

Station	Depth (in ft.)	Total silica	Quartz.	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Sakrand	0—1	61·41	34·77	26·64	7·54	17·36	2·81	0·79	1·83	1·59
2. Karachi		41·95	4·99	36·96	9·42	18·83	5·84	3·84	4·96	5·40
3. Peshawar		48·84	10·37	38·47	9·34	25·02	3·27	3·99	4·77	2·81
4. Pusa		37·03	4·44	32·59	10·74	21·67	7·59	5·41	1·92	7·53
5. Padrauna		39·97	13·34	26·63	11·30	14·09	7·77	4·20	4·10	3·47
1. Sakrand	1—2	59·17	29·01	30·16	8·69	19·81	2·17	0·78	2·60	2·40
2. Karachi		43·16	5·99	37·17	9·62	18·56	6·56	3·71	4·59	4·93
3. Peshawar		49·55	7·75	41·80	10·07	26·09	2·69	2·12	4·13	3·04
4. Pusa		40·32	7·48	32·84	10·52	19·17	8·18	2·97	4·28	3·78
5. Padrauna		59·09	28·51	20·58	7·51	9·85	13·86	3·36	3·12	2·80
1. Sakrand	2—3	55·05	21·14	33·91	9·17	21·94	2·95	0·82	2·72	2·49
2. Karachi		41·30	5·07	36·23	9·36	17·99	8·00	0·58	5·10	4·97
3. Peshawar		48·84	7·66	41·18	10·69	23·47	3·40	3·69	4·77	3·26
4. Pusa		46·61	15·81	30·80	10·83	17·82	6·88	3·42	2·94	3·44
5. Padrauna		41·97	27·16	14·81	5·63	7·22	20·91	2·70	2·73	2·20
1. Sakrand	3—4	60·27	24·97	35·30	8·41	19·99	1·45	0·55	2·13	3·11
2. Karachi		41·93	5·79	36·14	10·13	16·69	7·84	3·40	5·42	5·30
3. Peshawar		48·35	7·56	40·79	9·69	24·04	3·87	3·21	3·43	3·70
4. Pusa		40·46	11·65	28·81	9·56	12·20	12·31	3·56	7·45	4·24
5. Padrauna		40·96	30·61	10·35	4·19	4·51	24·76	2·27	2·21	1·49
1. Sakrand	4—5	57·72	20·13	37·59	8·52	21·12	1·50	0·53	2·50	3·56
2. Karachi		43·70	8·71	34·99	8·98	16·89	7·87	3·62	4·90	5·27
3. Peshawar		50·16	11·07	39·09	9·65	26·63	2·83	1·60	4·88	3·62
4. Pusa		42·18	14·48	27·70	9·85	13·32	13·18	1·84	3·65	6·35
5. Padrauna		50·91	36·37	14·54	3·93	6·55	19·77	2·59	2·63	1·88

CLAY ANALYSIS

AVERAGE VALUES

Soil type	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Arid Soils	0—1	49·70	12·01	37·69	9·41	21·80	2·34	2·39	4·03	4·22
	1—2	49·93	10·07	39·86	10·47	22·56	1·93	2·42	3·89	4·32
	2—3	50·65	11·06	39·59	10·29	22·38	1·73	2·16	3·26	3·80
	3—4	50·96	12·04	38·92	10·08	21·76	1·80	2·44	3·33	4·31
	4—5	51·43	14·62	36·81	10·44	20·90	1·81	2·35	3·60	4·41
Semi-arid	0—1	50·96	7·16	43·80	11·31	22·01	2·24	2·12	1·91	3·17
	1—2	51·37	6·85	44·52	11·64	23·10	2·00	2·10	2·02	3·15
	2—3	50·31	6·30	44·01	11·31	23·20	2·02	1·96	1·91	3·20

CLAY ANALYSIS—*contd*

AVERAGE VALUES —*contd*

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Soils	3—4	50·33	6·03	44·30	11·33	22·70	2·71	1·90	1·84	3·35
	4—5	49·09	7·35	41·74	11·04	21·41	3·81	1·98	1·92	3·59
	0—1	50·17	9·26	40·91	11·99	24·17	1·15	1·12	2·35	1·89
	1—2	48·77	6·39	42·38	11·98	26·83	1·16	1·08	2·30	2·07
Humid	2—3	48·83	6·11	42·72	12·02	26·58	1·00	1·04	2·48	2·32
Soils	3—4	48·64	6·10	42·54	12·52	26·45	1·14	1·22	2·12	2·05
	4—5	49·47	7·65	41·82	12·33	25·39	1·21	1·26	2·03	2·33
Per-humid	0—1	44·03	7·48	36·55	10·27	28·10	0·44	1·34	2·14	1·68
	1—2	45·74	9·31	36·43	9·09	29·56	0·36	1·08	2·45	1·65
Soils	2—3	46·11	9·78	36·33	9·91	29·47	0·34	1·06	2·33	1·44
	3—4	46·97	10·76	36·21	9·89	29·73	0·33	0·91	2·15	1·58
	4—5	47·21	11·33	35·88	10·67	29·97	0·34	0·90	2·03	1·76
	0—1	45·84	13·58	32·26	9·67	19·39	5·46	3·65	3·52	4·16
Calcareous	1—2	48·26	15·75	32·51	9·28	18·70	6·69	2·59	3·74	3·39
	2—3	46·76	15·37	31·39	9·14	17·69	8·43	2·84	3·65	3·29
Soils	3—4	46·40	16·12	30·28	8·40	15·49	10·05	2·60	4·13	3·57
	4—5	48·93	18·15	30·78	8·19	16·90	9·03	2·04	3·71	4·14

COLOUR CLASSIFICATION

Grey and pink soils

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Mianwali . . .	0—1	49·41	11·27	38·14	8·15	20·36	2·42	4·01	3·93	2·94
2. Gurdaspur . .		43·12	8·95	34·17	11·14	23·68	2·71	0·37	2·59	4·77
3. Lahore . . .		46·97	5·04	41·93	12·82	24·38	1·47	2·29	3·76	5·23
4. Mirpurkhas . .		50·29	12·45	37·84	9·23	23·51	2·69	0·80	3·45	2·71
5. Makrera . .		53·06	20·06	33·00	10·44	18·65	1·86	3·78	3·17	2·89
6. Rangpur . . .		50·06	31·80	18·26	12·49	22·56	0·61	3·50	3·88	2·36
7. Berhampur . .		55·19	10·29	44·90	11·79	19·08	0·94	0·66	3·24	3·29
1. Mianwali . .	1—2	53·03	13·32	39·71	7·61	21·32	2·38	4·41	3·18	3·28
2. Gurdaspur . .		45·87	5·24	40·63	12·91	28·10	0·75	0·36	2·59	4·24
3. Lahore . . .		47·82	5·07	42·75	13·24	24·87	1·07	3·10	3·40	4·05
4. Mirpurkhas . .		49·66	9·47	40·19	10·32	25·87	2·35	0·28	3·55	3·11
5. Makrera . . .		51·80	15·69	36·11	10·97	20·26	1·47	4·15	3·25	2·85
6. Rangpur . . .		50·50	23·83	26·67	8·90	23·00	0·30	1·29	5·78	3·11
7. Berhampur . .		51·40	5·74	45·66	10·46	24·65	0·77	0·58	2·74	2·33
1. Mianwali . .	2—3	53·21	13·99	39·22	7·67	20·20	3·00	3·69	3·26	1·72
2. Gurdaspur . .		46·17	5·93	40·24	11·67	28·64	0·77	0·48	2·58	5·02
3. Lahore . . .		47·91	5·49	42·42	11·27	27·72	0·95	0·71	4·95	3·45

COLOUR CLASSIFICATION—*contd*

Grey and pink soils—contd

Station	Depth (in ft.)	Total silica	Quartz.	Combined silica	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
4. Mirpurkhas . .	2—3	50·64	9·76	40·88	10·49	25·57	1·33	0·41	1·42	2·47
5. Makrera . . .		50·58	13·59	36·99	10·73	20·45	2·24	4·15	3·05	3·04
6. Rangpur . . .		51·70	12·20	39·50	8·80	22·10	0·32	1·74	4·71	0·86
7. Berhampur . .		52·62	4·96	47·66	9·78	25·00	0·68	0·59	2·97	2·62
1. Mianwali . .	3—4	51·00	12·04	38·96	7·46	18·78	3·35	4·77	2·32	2·97
2. Gurdaspur . .		46·69	6·08	40·61	12·65	28·18	0·72	0·37	2·39	4·70
3. Lahore . . .		49·42	6·98	42·44	12·18	26·16	0·85	0·71	4·16	4·16
4. Mirpurkhas . .		51·78	12·58	39·20	9·82	25·82	1·41	0·37	3·30	2·36
5. Makrera . . .		38·85	8·26	30·59	9·54	18·77	10·67	4·30	2·09	2·04
6. Rangpur . .		55·95	36·71	19·24	8·63	22·72	0·38	1·64	4·11	1·20
7. Berhampur . .		50·72	3·54	47·18	10·06	26·22	0·91	0·65	2·86	1·93
1. Mianwali . . .	4—5	51·49	20·45	31·04	5·44	18·77	3·21	4·42	2·99	4·32
2. Gurdaspur . .		46·37	7·76	38·61	12·44	26·83	0·75	0·47	2·70	5·25
3. Lahore . . .		48·19	5·95	42·24	10·84	27·60	1·18	1·15	3·83	3·54
4. Mirpurkhas . .		52·36	13·52	38·84	10·82	25·12	1·68	0·25	3·02	2·79
5. Makrera . .		39·85	16·54	23·31	8·20	13·70	14·85	4·64	1·70	2·18
6. Rangpur . . .		55·57	36·44	19·13	8·72	24·11	0·57	1·71	3·92	1·82
7. Berhampur . .		49·79	4·24	45·55	9·74	25·38	0·88	0·63	2·36	2·65

BLACK SOILS

Analytical values—per cent on dry clay

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Samalkot . . .	0—1	50·89	2·71	48·18	11·10	24·06	0·97	0·55	2·60	2·48
2. Nandyal . . .		53·88	2·53	51·35	11·07	26·26	1·64	0·57	1·08	4·09
3. Hagari . . .		53·08	3·36	49·72	10·40	22·02	2·75	0·37	0·83	3·76
4. Koilpatti . . .		55·24	5·45	49·79	7·79	22·08	2·28	4·71	0·92	2·86
5. Padegaon . .		51·00	1·69	49·31	11·00	19·17	3·22	4·89	0·66	3·22
6. Akola . . .		53·53	8·10	45·43	11·52	20·66	1·94	3·42	1·20	3·95
7. Surat . . .		47·84	3·42	44·42	14·45	24·21	2·87	1·12	0·66	0·17
8. Kharua . . .		51·00	8·03	42·97	8·70	20·09	4·09	3·46	2·18	1·65
9. Indore . . .		55·14	12·28	42·86	10·09	23·02	2·43	3·18	3·59	1·80
10 Nagpur . . .		50·03	5·01	45·02	13·81	24·00	1·29	0·36	1·15	1·53
11. Powarkhera . .		53·98	11·49	42·49	9·13	23·01	1·97	2·72	1·99	1·38
12. Kheri-adhartal .		51·99	7·26	44·73	13·47	23·46	1·72	0·60	1·18	1·38
1. Samalkot . . .	1—2	50·74	2·51	48·23	11·11	24·50	0·94	0·42	3·00	3·89
2. Nandyal . . .		52·38	3·54	48·84	11·63	26·19	1·67	0·65	1·14	4·75
3. Hagari . . .		50·68	3·36	47·32	11·81	25·44	4·73	0·40	1·24	5·32
4. Koilpatti . . .		56·39	8·26	48·13	7·71	21·08	2·09	4·60	0·97	3·20
5. Padegaon . .		51·02	1·63	49·39	10·95	19·56	3·00	4·80	1·00	4·10

BLACK SOILS—*contd*

Analytical values—per cent on dry clay— contd

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
6. Akola	1—2	53·42	8·22	45·20	12·20	22·08	1·44	2·24	1·08	2·61
7. Surat		50·95	3·41	47·54	16·15	21·86	1·08	1·34	0·65	3·00
8. Kharua		52·34	8·79	43·55	8·89	20·35	4·00	3·34	1·96	1·44
9. Indore		59·95	10·02	49·93	9·94	21·38	2·38	2·69	2·09	1·55
10. Nagpur		51·12	3·63	47·49	13·83	22·97	1·77	0·60	1·47	3·03
11. Powarkhera		56·23	16·10	40·13	8·87	22·77	2·03	2·31	1·67	0·74
12. Kheri-adhartal		56·23	5·83	44·40	13·41	25·36	1·56	0·43	1·02	0·97
1. Samalkot	2—3	50·63	2·46	48·17	11·83	25·89	0·85	0·33	2·98	3·56
2. Nandyal		51·50	2·80	48·70	11·13	25·90	1·35	0·90	1·02	4·29
3. Hagari		50·69	3·35	47·34	8·66	24·52	2·60	0·34	0·97	5·59
4. Koilpatti		55·17	8·73	46·44	6·80	20·38	3·17	4·21	0·94	3·08
5. Padegaon		52·22	1·66	50·56	11·42	18·47	2·91	5·03	0·47	3·66
6. Akola		53·41	7·33	46·08	13·08	21·27	1·63	2·79	1·81	3·28
7. Surat		50·39	2·73	47·66	16·16	22·22	0·94	1·08	0·80	2·36
8. Kharua		50·20	8·02	42·18	9·24	21·07	3·95	3·40	2·03	0·79
9. Indore		50·85	9·09	41·76	10·70	20·64	2·06	3·17	2·07	1·97
10. Nagpur		48·95	2·23	46·72	13·94	23·11	1·59	0·36	1·45	2·33
11. Powarkhera		56·39	14·80	41·59	9·29	21·84	1·84	2·20	1·45	0·98
12. Kheri-adhartal		51·20	7·06	44·14	13·40	23·94	1·81	0·61	1·49	2·06
1. Samalkot	3—4	..	..	..	..	..	..	..	..	..
2. Nandyal		53·23	2·64	50·59	11·08	25·43	1·32	0·49	0·89	5·16
3. Hagari		50·17	3·34	46·83	10·23	22·03	2·64	0·45	1·30	7·86
4. Koilpatti		54·01	6·06	47·95	6·52	20·10	4·28	4·87	0·97	2·63
5. Padegaon		52·21	1·69	50·52	11·42	17·85	2·93	4·37	0·71	2·82
6. Akola		52·91	6·26	46·65	12·46	22·56	1·69	2·02	1·45	2·26
7. Surat		50·47	3·16	47·31	15·82	23·29	0·80	0·93	0·89	1·91
8. Kharua		51·49	8·04	43·45	9·17	22·15	4·11	3·25	2·01	2·38
9. Indore		52·21	8·46	43·75	10·41	23·07	2·26	3·22	3·16	2·06
10. Nagpur		49·72	2·20	47·52	14·68	22·81	1·47	0·42	1·48	3·02
11. Powarkhera		54·80	11·99	42·81	10·12	22·11	2·09	2·60	1·42	1·43
12. Kheri-adhartal		53·03	6·19	46·84	13·61	23·32	1·68	0·42	0·84	0·72
1. Samalkot	4—5	..	..	..	..	..	..	..	..	..
2. Nandyal		53·06	4·77	48·29	10·94	26·96	1·40	0·33	0·83	4·30
3. Hagari		50·19	4·44	45·75	12·41	24·50	2·00	0·40	1·23	6·13
4. Koilpatti		54·23	5·16	49·07	6·10	19·66	4·44	4·91	1·00	3·09
5. Padegaon		37·98	4·04	33·94	7·89	12·95	10·31	2·67	0·72	4·45
6. Akola		51·50	3·72	47·78	13·00	20·83	1·99	2·61	1·52	2·85
7. Surat		50·87	3·31	47·56	14·93	20·79	1·05	1·40	1·16	2·24
8. Kharua		50·33	8·03	42·30	8·50	21·19	5·53	3·48	2·06	1·54
9. Indore		53·85	12·04	41·81	11·11	21·40	2·05	2·73	2·74	2·11
10. Nagpur		49·64	2·98	46·66	15·43	22·44	2·01	0·38	1·51	2·81
11. Powarkhera		53·49	13·40	42·09	9·77	22·42	2·83	2·84	1·33	1·53
12. Kheri-adhartal		55·65	11·65	44·00	13·16	22·64	1·55	0·41	0·87	1·28

BROWN AND REDDISH BROWN SOILS

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
	0—1									
1. Jorhat . . .		55·27	26·05	29·22	8·11	23·39	0·27	0·79	1·66	1·14
2. Sylhet . . .		40·50	4·25	36·25	8·61	30·00	0·24	1·43	2·16	1·24
3. Karimganj. . .		44·55	4·25	40·30	9·80	30·09	0·46	2·81	3·25	1·58
4. Waraseoni . .		42·57	2·26	40·31	12·37	27·14	1·33	1·16	2·75	2·56
5. Anakapalle . .		44·19	3·32	40·87	16·08	21·79	1·12	2·25	2·16	2·25
6. Coimbatore . .		55·26	12·00	43·26	10·30	23·67	0·68	0·32	0·97	0·84
7. Tabiji . . .		48·22	9·40	38·82	10·56	18·81	2·81	0·23	2·18	3·45
8. Delhi . . .		52·88	3·81	49·07	13·34	21·68	1·67	0·86	2·77	6·56
9. Shahjahanpur . .		54·19	22·42	31·77	10·97	19·70	0·92	2·34	4·32	2·06
10. Kangra . . .		46·44	7·21	39·23	10·74	25·86	1·38	0·12	2·25	3·89
11. Lyallpur . . .		50·78	12·11	28·67	10·07	21·23	1·52	1·60	3·65	7·72
12. Haripur (Haz) . .		48·31	12·21	36·10	10·19	22·08	2·73	3·13	5·10	3·52
	1—2									
1. Jorhat . . .		55·27	27·98	27·29	9·82	22·96	0·22	0·81	1·40	1·14
2. Sylhet . . .		44·50	4·04	40·46	7·07	34·85	0·18	1·55	2·99	0·24
3. Karimganj. . .		45·13	4·35	40·78	10·25	30·10	0·46	2·53	3·10	1·84
4. Waraseoni . .		41·94	1·40	40·54	13·16	29·17	1·03	1·28	2·45	2·41
5. Anakapalle . .		45·37	2·79	42·58	15·92	22·91	1·01	2·16	2·24	2·20
6. Coimbatore . .		52·87	8·42	44·45	11·18	25·09	0·86	0·33	0·52	0·78
7. Tabiji . . .		50·06	14·45	35·61	7·53	24·23	3·23	0·26	4·98	2·24
8. Delhi . . .		49·60	3·86	45·74	13·64	23·09	1·22	0·88	3·03	4·86
9. Shahjahanpur . .		46·12	7·60	38·52	12·87	29·27	0·68	2·29	4·10	1·51
10. Kangra . . .		47·96	9·18	38·78	10·74	25·29	1·29	0·23	2·30	3·67
11. Lyallpur . . .		49·98	11·57	38·41	12·66	19·39	1·46	1·46	3·39	7·25
12. Haripur (Haz) . .		47·03	5·91	41·12	11·20	23·67	1·53	3·54	5·45	3·65
	2—3									
1. Jorhat . . .		53·09	23·03	30·06	10·61	25·14	0·15	0·63	1·45	0·93
2. Sylhet . . .		48·72	4·19	44·53	6·65	33·59	0·10	1·57	2·15	0·78
3. Karimganj. . .		43·83	3·81	40·02	9·51	29·46	0·43	2·47	3·02	2·05
4. Waraseoni . .		42·67	1·33	41·34	12·25	29·72	0·97	1·12	2·31	2·38
5. Anakapalle . .		44·61	2·90	41·71	15·76	22·94	1·23	2·12	2·31	2·28
6. Coimbatore . .		53·33	10·12	43·21	10·02	25·60	1·51	0·30	0·60	1·34
7. Tabiji . . .		47·82	8·87	38·95	9·60	24·51	3·02	0·37	2·01	3·08
8. Delhi . . .		49·76	3·82	45·94	13·37	23·63	1·87	0·39	2·97	4·76
9. Shahjahanpur . .		44·42	5·58	38·84	12·98	31·26	0·50	2·37	6·26	..
10. Kangra . . .		49·91	9·84	40·07	10·44	25·28	1·12	0·11	2·24	3·77
11. Lyallpur . . .		50·88	13·10	37·78	11·80	20·16	1·27	1·12	3·44	7·14
12. Haripur (Haz) . .		47·88	7·40	40·48	11·18	23·58	1·33	3·43	1·90	3·89
	3—4									
1. Jorhat . . .		53·92*b*	26·16	27·76	11·93	23·51	0·20	0·60	1·34	1·08
2. Sylhet . . .		46·31	2·92	43·39	5·15	34·97	0·10	0·97	2·55	1·36
3. Karimganj . .		43·98	3·72	40·26	10·88	29·56	0·45	2·40	2·38	1·70
4. Waraseoni . .		42·71	1·81	40·90	11·84	30·08	0·92	1·10	2·68	2·45
5. Anakapalle . .		47·04	2·40	44·64	14·63	23·44	1·27	2·10	1·64	2·57

BROWN AND REDDISH BROWN SOILS—*contd*

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
6. Coimbatore	3—4	53·43	11·38	42·05	9·55	21·43	3·00	0·26	0·65	1·47
7. Tabiji		50·66	10·25	40·41	10·12	23·40	2·44	0·49	2·44	4·06
8. Delhi		52·14	5·48	46·66	14·18	21·79	1·85	0·59	2·92	4·24
9. Shahjahanpur		43·98	6·80	37·18	13·04	30·25	0·56	2·39	4·22	1·68
10. Kangra		49·06	11·11	37·95	10·79	26·00	1·12	0·20	2·15	4·03
11. Lyallpur		53·68	17·53	36·15	11·87	19·16	1·18	1·24	3·12	7·02
12. Haripur (Haz)		47·38	5·99	41·39	11·16	23·26	1·26	3·38	4·59	4·88
1. Jorhat	4—5	48·37	25·13	23·24	17·77	21·95	0·28	0·64	1·28	1·08
2. Sylhet		48·10	3·51	44·59	5·54	34·54	0·07	1·07	2·26	1·41
3. Karimganj		45·95	4·34	41·61	9·43	30·55	0·43	1·68	2·38	2·31
4. Waraseoni		42·28	2·68	39·60	12·28	29·62	0·93	1·07	2·66	2·39
5. Anakapalle		47·05	2·34	44·71	14·98	22·78	1·45	2·21	1·73	2·64
6. Coimbatore		..	..	..	..	..	..	..	..	..
7. Tabiji		52·07	18·99	33·08	9·68	19·25	3·42	0·29	3·01	5·73
8. Delhi		51·71	5·86	45·85	13·49	21·36	2·98	0·48	2·69	4·22
9. Shahjahanpur		45·30	8·63	36·67	12·59	29·31	0·54	2·52	4·42	2·34
10. Kangra		50·75	14·61	36·14	10·70	27·04	1·05	0·50	2·11	3·86
11. Lyallpur		54·63	18·60	36·03	13·72	15·85	1·21	1·42	2·91	6·89
12. Haripur (Haz)		47·26	5·92	41·34	11·79	23·87	1·14	3·32	5·49	3·65

IV. RED OR LIXIVIUM SOILS

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
1. Ranchi	0—1	47·04	9·51	37·53	11·63	28·67	1·37	1·34	2·21	0·98
2. Chandkhuri		45·54	14·47	31·07	14·67	25·47	0·11	0·49	1·72	1·88
3. Taliparamba		34·53	0·87	33·66	9·65	34·90	0·22	1·01	0·58	0·30
4. Sirsi		35·21	1·31	33·90	14·93	29·30	0·15	0·94	1·44	1·35
1. Ranchi	1—2	45·13	5·23	39·90	9·85	33·12	0·53	1·27	2·22	1·00
2. Chandkhuri		40·98	5·02	35·96	15·69	29·64	0·23	0·59	2·17	2·99
3. Taliparamba		38·68	0·87	37·81	10·14	36·86	0·13	0·78	0·76	0·27
4. Sirsi		38·42	1·92	36·50	14·91	31·35	0·16	1·12	1·57	1·25
1. Ranchi	2—3	47·72	9·25	38·47	10·09	30·95	0·37	1·15	2·53	1·03
2. Chandkhuri		41·64	5·53	36·11	15·37	29·02	0·22	0·43	2·05	4·23
3. Taliparamba		38·95	·85	38·10	10·70	37·18	0·32	0·66	1·33	0·42
4. Sirsi		38·45	2·24	36·21	15·51	30·59	0·18	1·11	1·70	1·36

IV. Red or lixivium soils—*contd*

Station	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	F_2O_7	Al_2O_3	CaO	MgO	K_2O	Na_2O
	3—4									
1. Ranchi		48·18	10·76	37·42	10·18	30·36	0·47	1·41	2·57	0·69
2. Chandkhuri		42·81	5·89	36·92	16·46	31·22	0·20	0·37	1·47	4·28
3. Taliparamba		40·79	1·15	39·64	9·41	37·13	0·14	0·27	0·98	0·50
4. Sirsi		38·05	1·76	36·29	15·12	31·78	0·10	0·98	1·67	1·28
	4—5									
1. Ranchi		51·25	14·97	36·28	9·25	28·05	0·60	1·28	1·95	0·84
2. Chandkhuri		43·32	2·71	40·61	16·99	24·60	0·22	0·32	1·56	5·63
3. Taliparamba		40·71	1·33	39·38	9·49	36·95	0·10	0·36	0·92	0·75
4. Sirsi		37·73	2·16	35·57	15·51	31·78	0·14	0·95	1·39	1·32

CLAY ANALYSIS

Average value

Soil type	Depth (in ft.)	Total SiO_2	Quartz.	Combined SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O
Grey and pink	0—1	49·77	11·27	38·50	10·87	21·75	1·81	2·20	3·43	3·46
	1—2	50·01	11·19	38·82	10·63	24·01	1·30	2·02	3·51	3·28
	2—3	50·17	12·22	37·95	10·06	24·24	1·33	1·63	3·28	2·74
	3—4	49·20	12·31	36·89	10·05	23·81	2·61	1·83	3·03	2·77
	4—5	49·18	14·99	34·19	9·46	23·07	3·30	1·90	2·93	3·22
Black soils	0—1	52·30	5·94	46·36	11·04	22·67	2·26	2·16	1·50	2·86
	1—2	52·96	6·28	46·68	11·38	22·79	2·22	1·99	1·44	2·88
	2—3	51·81	5·86	45·95	11·30	22·44	2·06	2·04	1·46	2·83
	3—4	52·21	5·46	46·75	11·41	22·33	2·30	2·09	1·37	2·93
	4—5	51·17	6·69	44·48	11·20	21·43	3·20	2·01	1·36	2·94
Brown and reddish brown soils	0—1	48·60	9·94	38·66	10·93	23·81	1·26	1·42	2·77	3·07
	1—2	47·98	8·46	39·52	11·25	25·84	1·10	1·44	3·00	2·65
	2—3	48·07	7·83	40·24	11·18	26·24	1·13	1·33	2·81	2·95
	3—4	48·70	8·80	39·90	11·26	25·57	1·20	1·31	2·56	3·04
	4—5	48·50	10·06	38·44	12·00	25·10	1·23	1·38	2·81	3·32
Red soils	0—1	40·58	6·54	34·04	12·72	29·59	0·46	0·95	1·49	1·13
	1—2	40·80	3·26	37·54	12·65	32·74	0·26	0·94	1·68	1·38
	2—3	41·69	4·47	37·22	12·92	31·94	0·27	0·84	1·90	1·76
	3—4	42·46	4·89	37·57	12·79	32·63	0·25	0·76	1·65	1·69
	4—5	43·25	5·29	37·96	12·81	30·35	0·27	0·73	1·46	2·14

A RELATIVE STUDY OF SOIL AND ARTIFICIAL MULCHES IN CONSERVING SOIL MOISTURE

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The effect of artificial mulches such as those of straw and paper has been studied in the western countries, more especially in the United States of America, in great detail. Harris and Jones [1918], working under dry farming conditions, came to the conclusion that straw mulches were more effective in preventing evaporation than soil mulches. Similar results were obtained by Martin [1935] in Africa, and Shaw [1929] in U.S.A. Smith [1931] studied the effect of paper mulches, and found them very efficient in conserving moisture. A conference on mulching was held in Leningrad, U.S.S.R., in 1932 and as a result of the discussions held there, it was agreed that paper mulches conserved more moisture, and were more effective than soil mulch. Maher [1936], while reviewing the work on mulches, also came to the same conclusion, i.e. artificial mulches conserve more moisture than soil mulch.

Recently, the researches of Blomqoist [1940] in Finland, Paul [1941] in Ceylon, Turner [1940] in Trinidad and Beach [1941] in U.S.A., again support the findings of other workers regarding the efficiency of artificial mulches. Russell [1940], however, maintains that artificial mulches are only effective during periods of frequent rains, but are of little value when rains are scanty.

No work of this nature has been reported from any quarters in this country. Therefore, experiments were conducted to study the relative effect of soil and artificial mulches under dry-farming conditions at Rohtak. The importance of this work is greatly enhanced, from the point of view of dry-farming studies, as the main problem in this case is to reduce evaporation to a minimum and conserve maximum amount of moisture received in the form of rainfall for the use of the crop. A detailed investigation on the relative effect of soil mulch and weeding out has already been submitted by the authors for publication, and the work reported here is in continuation of that work.

The experiments were carried out in (i) pots, (ii) observation plots, and (iii) randomized field experiments.

Experimental

I. Pot experiment

Twenty-four pots, each 18 in. long and 1 ft. in diameter were placed under the following treatments :

1. Artificial mulch 2 in. thick.
2. Artificial mulch 4 in. thick.
3. Soil mulch 2 in. thick.
4. Soil mulch 4 in. thick.
5. Soil mulch 6 in. thick.
6. Control (without mulch).

Each pot was filled with 80 lb. of medium loam soil, leaving 4 in. of empty space at the top. Mechanical composition of the soil is given below :

Clay	Silt	F. Sand	$CaCo_3$
(0·002 mm.)	(0.02 mm.)	(0·20)	..
16·31	35·80	50·38	0·22

There were four replications of each treatment, and the data was examined statistically. To each pot were added 18 lb. of water on 20 July 1937, and immediately after the addition, eight pots were covered with artificial mulch of *bajra* stalk (*Pennisetum-typhoideum*). The remaining pots came into 'wattar' condition on 26 July 1937, and excepting four pots which were to serve as controls, the others were cultivated to different depths to form soil mulch 2 in., 4 in. and 6 in. deep. The pots were kept in the open, but were embeded in the soil in order to ensure uniform conditions of temperature. They were weighed from time to time, and losses of moisture from them were determined. The results are given in Table I.

TABLE I

Loss of moisture from pots under straw and soil mulch in lb.

	First period 20 July 1937 to 9 May 1938											
	20/7 to 26/7 1937	9/8 1937	19/8 1937	31/8 1937	20/9 1937	13/10 1937	21/12 1937	12/1 1938	12/2 1938	12/3 1938	12/4 1938	9/5 1938
Artificial mulch 2 in.	1·89	2·06	4·12	1·87	+4·06	2·50	5·00	+3·19	1·87	1·56	1·56	0·80
Artificial mulch 4 in.	1·81	1·44	4·44	1·64	+3·00	3·62	5·56	+3·00	1·56	2·00	2·00	0·40
Soil mulch 2 in.	6·94	1·50	1·75	0·54	+1·62	1·06	4·00	+1·12	1·50	2·12	1·44	1·30
,, ,, 4 in.	7·12	2·19	2·31	0·17	+3·50	0·94	4·00	+2·31	1·19	1·56	1·81	2·41
,, ,, 6 in.	7·31	1·75	2·25	0·17	+3·75	1·00	3·75	+2·31	1·12	1·44	1·81	2·20
Control	7·12	4·25	3·94	0·86	+4·00	1·44	1·62	+2·81	1·38	1·31	1·12	0·72
Observed P	<0·01	<0·01	<0·01	<0·01	..	..	..	..	..	..	..	..
Critical difference	2·64	0·62	1·05	0·77	..	..	..	..	..	..	..	..
S. E. per cent mean	16·8	9·8	11·2	3·0	..	..	..	..	..	..	..	..
	Second period 10 May to 1 June 1938											
	10/5 to 13/5 1938	15/5 1938	17/5 1938	19/5 1938	21/5 1938	24/5 1938	27/5 1938	1/6 1938				
Straw mulch 2 in.	5·69	1·75	1·19	1·62	1·94	1·44	0·75	0·19	..	..	..	..
,, ,, 4 in.	4·75	1·60	1·31	1·13	1·88	1·50	1·13	0·62	..	..	..	
Soil ,, 2 in.	7·38	0·62	0·69	0·62	0·75	0·81	0·69	0·50	..	..	..	.
,, ,, 4 in.	8·81	0·81	0·19	0·56	0·69	0·81	0·62	0·13	..	..	..	..
,, ,, 6 in.	8·69	1·06	0·25	0·50	0·69	0·56	0·50	0·25	..	..	..	..
Control	9·06	2·13	1·13	0·56	0·88	0·44	0·62	0·13	..	..	..	..
Observed P	<0·01	<0·01	<0.01	<0·01	..	..	..	..	..	..	..	..
Critical difference	0·35	0·48	0·42	0·23	..	..	..	..	..	..	..	..
S. E. per cent mean	9·20	21·80	17·6	6·6	..	..	..	..	..	..	..	..

First period 20 July 1937 to 9 May 1938

There was intense evaporation from all the pots other than those under artificial mulch from 20 to 26 July 1937. The loss of moisture during this interval was significantly less from pots under artificial mulch than from pots under other treatments (from which the loss was nearly the same). The loss of moisture from the pots under artificial mulch and those under soil mulch and the control was 1·25, 7·12 and 7·12 lb. respectively. When pots were weighed after 14 days on 9 August 1937, the loss of moisture due to evaporation from the pots under all the treatments was the same except from the controls, which recorded greater losses. On 19 August 1937 (a month after the start of the experiment), the losses from the pots under artificial mulch became more than those under soil mulch, and were almost equal to those from controls. On 31 August 1937 (a month and a half after the start of the experiment), the losses of moisture from the artificial mulch became significantly higher than those under all the other treatments. From this date onward till 9 May 1938, the losses from artificial mulch remained the highest, followed by those under soil mulch, and were lowest in the case of control pots except after a shower of rain on 18 September 1937, when the evaporation from the controls was slightly more than those under soil mulch, but the differences were not significant statistically.

Second period 10 May to 1 June 1938

It was decided to study the effect of artificial mulches on the conservation of moisture during the driest and the hottest month of the year, but

it was observed that bulk of the water had already evaporated from the pots, and moisture content had fallen much below the wilting coefficient (5·37 per cent). Therefore, 19 lb. of water were added to each pot on 10 May 1938. Soil became fit for cultivation on 13 May 1938, and soil mulch was formed in pots under this treatment. Losses of moisture from 10 to 13 May 1938 were least from the pots under artificial mulch. These results again support the observation already made, viz. the loss of moisture under artificial mulch is least in the beginning. However, one noteworthy difference is, that the absolute loss from all the pots was higher during this period of three days than it was in six days interval from 20 to 26 July 1937. On 15 May 1938, two days after the formation of soil mulch, the evaporation from the pots under artificial mulch became more as compared to soil mulched pots, but was less than those of controls. However, on 17 May 1938, the loss from pots under straw mulch, became even more than the control pots. Loss of moisture remained highest from straw mulch till 27 May 1938, when it became more or less the same from other treatments.

When straw mulch 2 in. thick is compared with 4 in. thick it is observed, that there are more losses from 2 in. thick mulch in the beginning, but after 10 to 15 days these become more from 4 in. straw mulch. In the hot season total loss of moisture was more from 2 in. straw mulch. A 2 in. mulch is quite adequate in winter, but during the summer 4 in. mulch is decidedly better. Harris and Bracken [1917] recommend 2 in. thick layer of straw, but the results at this station show that thickness of mulch depends on the season.

Absorption of rain water

All the pots were weighed on 20 September 1937 and 12 January 1937, after 2·69 and 1·10 in. of rains respectively. The results show that there was more absorption of rain water under straw mulch. The data obtained on 20 September 1937 is not significant but those obtained on 12 January 1937 gave statistically significant figures.

Total loss of water from the pots during the first period from 20 July 1937 to 9 May 1938

Total loss from each pot on different dates, and the percentage loss of the water added for both the periods are given in Table II.

When the pots under straw mulch are compared with those under soil mulch it will be seen that the total amount of water lost remained less from pots under straw mulch from 20 July to 31 August 1937. On this date, 53·4 and 62·8 per cent of the total water added had evaporated from straw, and soil mulch respectively. Later on the total amount of water lost from straw mulch became more, and on 12 April 1938, 22·6 lb. of water were lost as against 20·9 lb. from soil mulch, which means an extra loss of 2 lb. of water under straw mulch. The straw mulch pots did not show any marked variation amongst themselves.

TABLE II

	Total loss of moisture from 20 July 1937								
	20/7 1937	9/8 1937	19/8 1937	31/8 1937	13/10 1937	2/12 1937	12/2 1938	12/3 1938	12/4 1938
Artificial mulch 2 in.	1·88	3·94	8·06	9·94	12·44	17·44	19·31	20·94	22·44
,, ,, 4 in.	1·81	3·25	7·69	9·31	12·94	18·50	20·06	20·14	22·88
Soil ,, 2 in.	6·94	8·44	10·19	11·69	11·75	15·75	17·25	19·47	20·81
,, ,, 4 in.	7·12	9·31	11·62	11·75	12·60	16·60	17·88	19·14	21·25
,, ,, 6 in.	7·31	9·06	11·31	11·44	12·44	16·19	17·31	18·59	20·56
Control	7·12	11·38	15·31	15·94	17·38	17·35	20·38	20·18	21·08
Observed P	$<0·01$	$<0·01$	$<0·01$	..	$<0·05$	$>0·05$	$>0·05$	$>0·05$	$>0·05$
Critical difference	2·64	2·94	2·56	..	2·73	..	..	..	..
S. E. of mean	16·8	13·2	8·80	..	6·9	8·2	4·2	4·5	3·9
	Percentage loss of moisture of the total water added on 20 July 1937								
Artificial mulch	10·3	20·0	43·8	53·5	70·5	99·8	109·4	114·1	125·9
Soil mulch	39·5	49·6	61·3	62·7	68·3	90·0	97·1	105·9	116·0
Control	39·6	63·2	85·0	88·5	96·6	105·6	113·2	112·1	126·7

TABLE II—*contd.*

	Total loss of moisture from 10 May 1938							
	10/5 to 13/5 1938	15/5 1938	17/5 1938	19/5 1938	21/5 1938	24/5 1938	27/5 1938	1/6 1938
Straw mulch 2 in.	5·69	7·44	8·63	10·25	12·19	13·63	14·50	14·75
,, ,, 4 in.	4·75	6·25	7·50	8·50	10·31	12·00	13·13	13·56
Soil ,, 2 in.	7·38	8·00	8·69	9·38	10·12	10·94	11·63	12·12
,, ,, 4 in.	8·81	9·63	9·75	10·31	11·00	11·81	12·44	12·56
,, ,, 6 in.	8·69	9·69	9·94	10·44	11·12	11·69	12·19	12·44
Control	9·06	11·19	12·31	12·88	13·75	14·19	14·81	15·00
Observed P	$<0·01$	$<0·01$	$<0·01$	$<0·01$	$<0·01$	$<0·01$	$<0·01$	$<0·01$
Critical difference	0·80	0·44	0·31	0·63	0·98	1·05	1·05	1·05
S. E. of mean	3·8	5·4	3·4	2·2	2·8	2·7	2·6	2·5
	Percentage loss of moisture of the total water added on 10 May 1938							
Straw mulch	29·0	38·0	44·8	52·1	62·5	71·2	76·8	78·7
Soil mulch	46·0	50·6	52·5	55·8	59·8	63·8	67·2	68·7
Control	50·3	62·2	69·3	71·5	76·4	79·7	82·3	83·3

From pots under soil mulch 39·5 per cent of the total water added had disappeared within six days, the time required for attaining 'wattar' condition and the preparation of soil mulch. After the formation of soil mulch the rate of evaporation greatly slowed down from these pots. From 26 July to 9 August 1937 loss from soil and artificial mulched pots amounted to 10·4 and 9·7 per cent and that from 9 to 19 August 1937 amounted to 11·7 and 23·8 per cent respectively, of the total water added.

In the controls moisture losses were more, and on 31 August 1937 water lost was 88·8 per cent, while in the case of pots under artificial mulch and soil mulch it was 53·4 and 62·8 per cent respectively. This difference narrowed down with time and on 2 December 1937, the total water lost from all the pots became the same.

Total loss of water from pots during second period from 10 May to 1 June 1938

The straw mulched pots lost 27·2 per cent of the total moisture from 10 to 13 May 1938, a period which took other pots to come into 'wattar' condition. During the same period, the soil mulched and control pots lost 45·1 and 46·3 per cent of the total water added. The total percentage loss remained less in straw mulch till 21 May 1938, when it became equal to the water lost from pots under soil mulch. On this date the percentage moisture lost from straw and soil mulch was 58·4 and 58·3 per cent respectively. Later on, the total water lost became more from straw mulch. On 1 June 1938, 73·2 and 67·1 per cent of water added was lost from the pots under straw and soil mulch respectively. After the formation of soil mulch the evaporation from these pots decreased considerably. From 13 to 15 May 1938 there was a loss of 4·4 per cent from the pots under soil mulch, while from the pots under straw mulch loss was 8·1 per cent. Later on, losses from soil mulch on different dates amounted to 2 to 3 per cent, while from straw mulch they varied from 5 to 9 per cent. On the other hand, in controls there was a gradual loss.

The water lost between different dates went on decreasing with time, and it ranged between 10·9 and 1·0 per cent during 15 May to 1 June 1938. Total water lost during this period from pots under straw, soil mulch, and controls was 73·2, 67·1, and 76·7 per cent respectively, the loss being maximum from controls, and minimum from soil mulch.

Meteorological factors and evaporation

When the rate of evaporation during the two periods is compared, it will be observed that greater evaporation takes place in the second period than in the first. During the first six days of the first period from 20 to 26 July 1937, there was loss of 10·4, 39·5, and 39·5 per cent as against 27·2, 45·1, and 46·3 per cent in first three days of

the second period (10 to 13 May 1938) from pots under straw mulch, soil mulch, and controls respectively. After a period of 19 days, percentage loss of water in the first period was 19·8, 49·6, 63·2, and in the second period it was 74·7, 65·4, and 75·3 per cent, from the straw mulched, soil mulched and control pots respectively. From the meteorological data given in Table III it will be seen that dry conditions prevailed in the second period and it is due to this intense drought that greater losses occurred.

TABLE III

Dates	Temperature		Relative humidity	Saturation deficit	Wind velocity
	Max.	Min.			
20 July to 19 August 1937	95·8°F.	79·5°F.	73	14·12	6·5
10 May to 6 June 1938	108·0°F.	80·8°F.	34	30·04	10·2

The dry weather increased evaporation much more in pots covered with artificial mulch than in others. The increase in loss through evaporation in the second period (due to more dry conditions) when compared with the first was more from pots under straw mulch than soil mulch or control pots (51·9 per cent in straw mulch as again 15·8 and 12·1 per cent from the soil mulch and control pots respectively).

Distribution of moisture in different layers

In order to ascertain the distribution of moisture in pots under different treatments, soil samples were obtained, in three sections, 0-3 in., 3-6 in. and 6-12 in. The first sampling was done on 13 October 1937 when the sowing of winter crops starts, and the second on 9 May 1938, when maximum amount of moisture had evaporated. The results are given in Table IV.

TABLE IV

Moisture as percentage on oven dry soil

	Artificial mulch		Soil mulch			Control	Observed P	C. D.	S. E. mean
	2 in.	4 in.	2 in.	4 in.	6 in.				
				13 October 1937					
0-3 in.	14·00	13·64	7·59	7·84	7·17	2·97	$<0·01$	3·76	12·6
3-6 in.	13·25	15·73	9·83	10·18	9·66	9·09	$<0·01$	2·68	8·1
6-12 in.	14·54	14·79	10·13	12·96	13·03	9·98	$<0·01$	2·48	6·5
				9 May 1938					
0-3 in.	0·91	0·94	0·62	1·09	1·56	0·64	$<0·05$	0·59	20·8
3-6 in.	1·97	1·55	1·41	1·95	2·57	1·34	$<0·05$	0·84	15·5
6-12 in.	3·94	3·76	3·05	3·47	3·85	3·23	$<0·05$	0·61	6·2

On 13 October 1937, moisture in all the layers of pots under straw mulch was much higher than those under soil mulch, or controls. In 0-3 in. layer of pots under straw mulch moisture was 14·00 to 13·64 per cent, while under the soil mulch and the controls it was 7·60 and 2·97 per cent respectively. In one foot layer, there was about 4 and 6·5 per cent more moisture present in pots under straw mulch, than those under soil mulch or controls respectively. Moisture under cover of 2 in. and 4 in. thick straw mulch was the same.

Under soil mulch there was about 2 per cent more moisture than in controls. In pots under soil mulch of different depths, there was no difference except in 6-12 in. layer of the pots under 2 in. soil mulch, in which case there was about 3 per cent less moisture than that under 4 in. or 6 in. soil mulch.

On 9 May 1938 moisture fell much below the wilting coefficient in all the depths. At this stage there was no significant difference between the moisture content of pots under artificial or soil mulch, though the pots under mulches contained more moisture when compared to controls, but significant differences were observed only betwen 6 in. soil mulch and control. These results suggest that in summer season a deeper layer of soil mulch is more effective.

II. *Observation plots*

In September 1937 plots measuring 33 ft. × $16\frac{1}{2}$ ft. were laid out in fields 92 and 78, representing two extreme types of profiles met at the station.

Mechanical analysis of these types is given in Table V.

Table V

Mechanical analysis

(Percentage on oven dry soil)

	Field No. 78				Field No. 92			
	Clay 0·002 mm.	Silt 0·02 mm.	F. Sand 0·2 mm.	C. Sand 0·4 mm.	Clay 0·002 mm.	Silt 0·02 mm.	F. Sand 0·2 mm.	C. Sand 0·4 mm.
0-6 in. . .	9·25	24·30	65·38	1·07	16·31	35·80	50·38	—
6-12 in. . .	13·50	19·32	67·50	1·59	21·65	40·04	38·25	0·05
2 ft. . .	21·02	22·36	54·95	1·08	34·08	32·58	31·52	0·53

In each of these fields two plots were laid out, one was covered with a 3 in. thick layer of plant trash, and the other occasionally cultivated 3 in. deep to form soil mulch. The covering was done immediately after a shower of 2·19 in. on 16 September 1937, and the soil mulch was produced with the help of a spade as soon as the plots attained 'wattar' condition. Moisture was estimated on different dates down to 2 ft. depth, and results are given in Table VI.

The data from the plots support the results already obtained from the pot experiments. There has always been more moisture in artificial mulch plots than soil mulch throughout the period from 18 September 1937 to 17 June 1938. Differences were more marked after the winter rains on 1 January 1938 than during the period from 18 September 1937 to 1 January 1938. From 1 January to 17 June 1938, the differences were more in the heavy type than in the light type except on 26 January 1938, when there was 0·73 per cent more moisture in the light type than heavy type in 2 ft. column of the soil. From 5 to 25 April 1938 there were no differences in the case of light type, but from 25 April 1938 onwards again differences developed, and moisture in artificial mulched plots became more than soil mulched plots, and this difference persisted till 7 June 1938. In the heavy type, moisture in the artificial mulched plots remained always more than soil mulched plots, the difference on 7 June 1938 in 0-6 in., 6-12 in. and 2nd ft. being 2·09, 3·09 and 1·67 per cent respectively. On the same day in the corresponding layers of light type the differences were much less (being 0·09, 0·42 and 0·37 per cent respectively).

Table VI

Observations plots.

(Percentage on oven dry soil)

Dates (1937-38)	18·9	30·10	2·12	3·1	28·1	25·2	26·3	5·4	15·4	25·4	5·5	15·5	27.5	7·6		
							Field No. 92									
Artificial mulch . .	0-6 in.	22·10	10·51	7·53	6·69	12·44	13·08	12·42	12·15	11·52	10·46	9·46	8·33	6·31	6·87	5·02
Soil mulch . . .	0-6 in.	18·66	8·97	7·07	6·48	17·24	10·98	6·97	4·05	4·05	4·59	5·57	3·22	3·57	2·87	3·11
Artificial mulch . .	6-12 in.	21·68	14·66	12·15	9·48	15·56	12·12	12·84	11·87	12·05	11·90	13·54	10·19	7·90	8·21	8·28
Soil mulch . . .	6-12 in.	10·02	13·13	12·22	10·37	14·44	11·61	9·83	10·34	7·23	9·15	9·24	5·07	8·37	5·94	5·19
Artificial mulch . .	2nd ft.	20·20	17·38	15·51	6·34	14·48	14·96	15·82	12·28	15·34	15·97	15·48	13·16	12·80	13·23	12·07
Soil mulch . . .	2nd ft.	14·20	14·61	14·77	12·33	12·65	12·34	11·67	14·75	11·36	11·71	11·30	9·81	10·65	9·96	10·40
							Field No. 78									
Artificial mulch . .	0-6 in.	15·35	8·86	6·40	6·27	14·44	13·28	10·95	5·91	5·00	4·66	6·57	5·66	3·61	3·14	2·65
Soil mulch . . .	0-6 in.	16·00	7·20	5·32	4·27	15·50	8·92	3·75	4·04	4·54	4·50	3·95	2·70	2·47	2·56	2·56
Artificial mulch . .	6-12 in.	15·57	11·04	9·03	8·67	12·08	12·35	12·25	7·90	7·93	6·63	8·98	8·56	5·94	5·26	4·91
Soil mulch . . .	6-12 in.	16·42	10·33	8·47	7·71	13·25	10·01	8·07	5·60	7·15	5·29	6·05	3·59	5·84	4·20	4·43
Artificial mulch . .	2nd ft.	15·50	12·98	11·20	10·35	11·08	11·87	11·82	10·09	10·66	10·15	9·67	12·93	9·10	8·47	8·26
Soil mulch . . .	2nd ft.	16·52	12·10	10·48	10·03	11·06	10·32	9·82	9·79	10·00	7·97	9·08	7·54	8·86	8·12	7·89

III. Randomized field experiments

Two types of soil, light loam and medium loam, were selected for this work. In each type of soil eight plots were laid out, and the treatments were arranged in paired groups, four plots being under each treatment. The size of each plot was 33 ft. × 10 ft. The experiment was started in the beginning of March 1939. Instead of *bajra* stalks, which were used in the observation plots, cotton stalks were used as artificial mulch.

Soil moisture 1939-40

Moisture determinations were started from 27 March 1939, and were carried out till 1 April 1940, when cotton was sown in these plots. During this interval 20 samplings down to 3 ft. depth were made and moisture determined. The results are given in Tables VII (*a*) and VII (*b*).

Before 27 March there were 1·42 in. of rain which were received in four showers. Due to these rains there was increase in all the layers down to 3 ft. in plots under artificial mulch in the light type, but in the case of heavy type there were no differences. There were differences in the moisture content of all the layers of the light type till 12 April, but on 30 April they disappeared in 0-6 in. layer, though differences in the lower layers were significant. Summer rains started from 6 June 1939, and the moisture estimated on 30 June after 2·79 in. of rains showed that though there was more moisture in the artificial mulched plots in the light type yet there were no such differences in the case of heavy type. Due to subsequent rains the differences between the artificial and soil mulched plots of the heavy type also became significant on 19 July 1939. The differences were more in the heavy type than in the light type.

From 19 July to 2 August there were no rains, and the results of moisture estimated on 22 August show that there was no difference in the artificial mulched and soil mulched plots of the light type, though there were significant differences in the case of the heavy type. From this date onward there were no significant differences, but after a shower of 1·09 in. on 18 September differences again became significant in both the soils, and they persisted till 19 October. On this day there was more moisture in the artificial mulched plots down to 2 ft. depth. There were no significant differences from 19 October 1939 to 13 February 1940. During this period though the differences were not significant there was more moisture in the artificial mulched plots and the differences were more in the heavy type than in the light type in which differences were small and insignificant. Moisture estimated on 13 February after 3·03 in. of rains showed that the differences between the treatments had become again significant, and there were significant differences in each layer down to 3 ft. depth. These differences persisted till 30 March 1940 when cotton was sown in the light type. Maximum differences occurred in the surface 6 in., and they decreased with the depth. Saving of moisture due to artificial mulch in 3 ft. column of light and heavy types was 2·11 and 1·26 per cent respectively.

Moisture estimated after the rains showed that there was always more moisture (2 to 3 per cent), and it travelled to deeper depths in the artificial mulched plots than in the soil mulched plots. During rainless periods there were losses of moistures from the plots under both the treatments, but the losses were more from artificial mulch than from soil mulch.

Soil moisture 1940-41

After the harvesting of cotton, moisture was estimated on 25 December 1940 (Table VIII), and on this date there was no difference between the moisture content of the mulched and the unmulched plots. Mulch was spread on 19 January 1941 after 2·42 in. of rains. Moisture estimated on 14 February 1941 showed that there was more moisture in the plots under artificial mulch. From 14 February to 18 September 1941 moisture was determined after a shower of rain, and the results obtained show that there was more moisture in all the layers of the artificial mulched plots. From 18 September to 8 November 1941, there were no rains, and the moisture estimated on 8 November 1941 showed that there were no significant differences between the moisture content of plots under both the treatments. In the upper first foot layer there was slightly more moisture in the plots under soil mulch but in the third foot layer of the artificial mulches there was 1 per cent more moisture. There was always more absorption of rain water by the plots under artificial mulch, and these results support the data obtained in the previous years.

Discussion and conclusion

According to Leather [1908] capillarity starts from the surface, and suction pressure is developed as a result of increased curvature of water films caused by the evaporation of water from the soil

TABLE VII(a)

FIELD No. 78

Field experiment I

(Moisture as percentage on oven dry soil)

Dates (1939-40)	27·3	12·4	30·4	30·6	19·7	2·8	12·8	28·8	12·9	22·9	19·10	17·11	18·12	21·1	13·2	24·2	4·3	19·3	30·3
Rain fall (in.)	1·42	..	..	2·79	1·75	..	0·87	0·16	0·67	1·09	..	..	..	0·59	3·03	..	..	1·79	..
0-6 in.																			
Artificial mulch	11·93	5·41	3·79	9·69	15·60	6·90	8·80	5·90	5·74	8·58	4·29	4·62	4·69	8·05	18·02	14·74	11·98	15·51	11·60
Soil mulch	8·84	3·99	3·72	6·66	13·25	5·42	7·44	5·47	4·99	5·81	3·52	4·02	4·46	7·82	13·09	9·15	8·02	9·33	8.31
Observed value of P	<0·05	<0·05	>0·05	<0·05	<0·01	>0·05	<0·05	>0·05	..	<0·08	<0·01	>0·05	..	>0·05	<0·01	<0·01	<0·01	<0·01	<0.01
S. E. per cent mean	0·8	7·1	7·5	7·5	5·4	8·0	3·6	2·4	..	3·0	5·8	5·6	..	3·7	2·5	5·0	3·0	5·4	3·7
6-12 in.																			
Artificial mulch	11·37	8·96	7·22	10·71	14·60	9·18	10·42	8·32	8·25	10·02	6. 91	7·15	7·40	7·37	16·04	14·49	13·24	14·68	12·69
Soil mulch	9·99	6·85	6·23	8·80	12·07	8·37	9·71	7·98	7·64	8·58	4·63	7·23	7·51	7·15	13·60	12·06	11·12	12,18	10·65
Observed value of P	..	..	>0·05	<0·05	..	..	>0·05	..	..	..	<0·05	..	..	..	..	..	..	..	<0·05
S. E. per cent mean	..	..	6·3	0·6	..		4·5	..	..	..	9·8	..	..	..	..	..	..	..	5·8
2nd ft.																			
Artificial mulch	11·51	10·70	9·82	10·81	13·26	11·49	11·15	10·19	10·05	9·71	9·54	9·87	9·78	9·78	15.51	13·41	12·95	15·08	14·09
Soil mulch	10·51	9·14	8·65	7·96	9·93	10·25	9·94	9·39	9·74	9·09	8·37	9·62	9·80	9·38	13·29	13·40	12·32	13·13	12·17
Observed value of P	..	..	..	<0·05	..	..	<0·05	..	..	..	<0·05		..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	9·5	..	..	2·5	..	..	..	4·7		..	..	..	..	..	..	5·3
3rd ft.																			
Artificial mulch	12·18	11·91	11·74	11·65	12·74	12·34	12·21	11·53	..	10·72	[illegible]	11·65	11·98	11·59	14·65	14·57	14·22	15·29	14·10
Sail mulch	11·74	11·31	10·88	10·71	10·79	11·12	11·17	10·61	..	10·38	10·57	11·28	11·69	11·35	12·43	13·07	12·28	12·68	12·35
Observed value of P	..	..	..	<0·05	..	..	>0·05	..	..	..	>0·05	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	3·9	..	..	3·8	..	..	..	2·1	..	..	..	..	..	..	..	7·7

TABLE VII (b)

FIELD No. 92

Field experiment I

(Soil moisture as percentage on oven dry soil)

Dates (1939-40)	27·3	12·4	30·4	30·6	19·7	2·8	12·8	28·8	12·9	22·9	19·10	17·11	18·12	18·1	21·1	13·2	24·2	4·3	19·3	30·3
0-6 in.																				
Artificial mulch	11·39	7·63	3·61	7·27	19·16	10·20	11·50	7·18	8·36	11·52	7·01	6·37	6·57	6·33	11·96	20·83	17·21	13·87	18·64	15·04
Soil mulch	10·72	7·62	4·65	5·63	16·84	6·49	9·53	5·54	7·08	9·98	4·38	4·99	5·79	5·28	10·61	18·88	14.19	10·95	15·54	13·05
Observed value of P	>0·05	..	..	>0·05	<0·05	<0·01	>0·05	>0·05	>0·05	<0·01	<0·01	>0·05	>0·05	>0·05	>0·05	<0·01	<0·05	>0·05	<0·05	<0·05
S. E. per cent mean	4·0	..	..	4·1	2·5	7·4	9·5	12·1	5·6	0·8	6·9	11·2	9·1	14·8	5·3	0·9	4·3	11·2	4·4	3·2
6-12 in.																				
Artificial mulch	11·88	9·75	7·40	7·32	16·64	11·71	12·61	10·07	9·66	13·01	9·20	8·96	9·36	8·19	8·67	20·26	17·81	15·68	19·26	17·76
Soil mulch	13·26	9·82	7·84	6·52	13·12	9·52	11·21	9·51	9·39	12·01	7·34	8·59	9·17	7·93	9·40	18·12	17·76	15·81	18·02	15·96
Observed value of P	..	..	..	>0·05	..	..	<0·05	..	..	..	>0·05	..	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	6·3	..	..	2·9	..	..	..	9·7	..	..	..	..	..	..	..	..	2·4
2nd ft.																				
Artificial mulch	9·17	9·22	8·12	6·52	11·90	11·96	11·78	11·82	11·02	12·15	11·54	11·39	11·68	10·13	10·64	17·58	16·54	15·43	17·64	16·89
Soil mulch	11·20	10·69	8·90	6·96	10·61	10·01	10·78	10·31	10·48	11·37	9·31	11·26	10·88	10·00	10·83	14·85	16·34	14·92	16·91	15·81
Observed value of P	..	..	..	>0·05	..	..	<0·05	..	..	..	<0·05	..	..	..	..	..	..	..	..	>0·05
S. E. per cent mean	..	..	..	6·3	..	..	1·8	..	..	..	6·8	..	..	..	..	..	..	..	..	4·9
3rd. ft.																				
Artificial mulch	11·78	10·89	8·49	7·01	11·85	11·57	12·09	12·22	..	12·73	11·59	12·84	14·41	12·62	13·29	14·68	15·45	15·80	16·50	15·89
Soil mulch	13·12	11·82	8·66	8·18	12·02	11·73	11·83	11·81	..	12·25	10·64	12·31	12·26	12·15	12·53	12·72	13·98	14·05	14·39	14·59
Observed value of P	..	..	..	>0·05	..	..	>0·05	..	..	..	>0·05	..	..	..	..	..	..	..	..	<0·05
S. E. per cent mean	..	..	..	8·4	..	..	3·1	..	..	..	5·4	..	..	..	..	..	..	..	..	1·7

Table VIII

Field experiment II

(Moisture as percentage on oven dry soil)

Dates	14/2/41	18/5/41	16/6/41	13/8/41	18/9/41	8/11/41
			0-6 in.			
Rain fall	0·82	2·26	2·51	5·36	3·02	nil
Artificial mulch	14·79	13·24	13·79	17·42	13·06	3·85
Soil mulch	10·56	8·23	7·61	15·11	10·85	4·71
Observed value of P	<0·01	<0·01	..	<0·01	<0·01	<0·05
S. E. per cent mean	1·3	5·1	..	4·0	3·7	14·9
			6-12 in.			
Artificial mulch	13·21	11·36	13·75	15·10	14·17	7·81
Soil mulch	10·96	8·71	11·11	12·83	12·51	8·61
Observed value of P	<0·05	..	..	..	<0·05	..
S. E. per cent mean	3·8	..	..	..	3·2	..
			2nd ft.			
Artificial mulch	8·94	9·16	12·56	13·86	14·65	11·22
Soil mulch	7·98	7·64	9·90	11·89	13·26	11·22
Observed value of P	>0·05	..	..	..	<0·01	..
S. E. per cent mean	10·0	..	..	..	2·2	..
			3rd ft.			
Artificial mulch	7·59	7·91	8·86	10·04	13·86	12·27
Soil mulch	8·14	7·74	8·26	9·34	11·33	11·28
Observed value of P	> 0·05	..	..	..	<0·01	<0·05
S. E. per cent mean	5·1	..	..	..	5·1	2·4

surface. This pressure decreases with the depth. Consequently water can rise to the surface only from a limited depth. The effect of mulches will therefore be limited to the depth from which water can rise, and will be more effective in the surface layer than in the lower layers. The results of experiments conducted by us support the conclusions drawn by Leather and further supported by the work of Sen [1930] and Carbery and Chakladar [1936]. Differences in the moisture content of soil mulched and artificial mulched plots on different dates are given in Table IX.

Table IX

(Moisture as percentage on oven dry soil)

Dates	0-3 in.	3-6 in.	6-12 in.	2nd ft.	3rd ft.
24 February 1940	7·06	5·59	2·43	0·01	1·57
4 March 1940	4·83	3·96	2·12	1·63	1·94
30 March 1940	5·94	3·29	2·04	1·92	1·75

These data clearly show that due to mulching there can be more moisture in the upper layers than in the lower layers, and conservation effect of mulch starts from the surface.

The results of pot and field experiments show that soil under artificial mulch can absorb more water than under soil mulch, as the water which passes through a layer of artificial mulch is protected from direct heat of the sun and the desiccating influence of the wind. Soil temperatures under artificial mulch are always lower than those under soil mulch or unstirred plots (Fig. 1). Therefore, after the rains the moisture under artificial mulch is always higher. During winter when conditions are less dry there is more absorption of water than in summer when comparatively dry conditions prevail.

When rains stop, there is intense evaporation due to increase in atmospheric temperatures, fall in relative humidity, and higher status of moisture in soil. During this period soil is too wet,

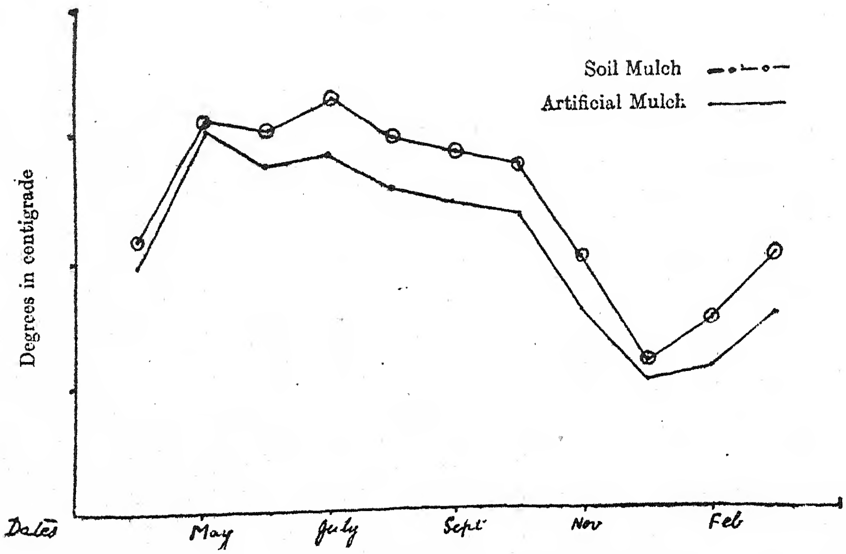

FIG. 1. Soil temperatures

and cannot be cultivated to form a mulch. Till it attains that condition (3-6 days period), 39·5 to 46·3 per cent of the total moisture present is lost. During the same period the losses from the artificial mulch are 10·4 to 27·2 per cent. After the formation of soil mulch, losses become more from the soil under artificial mulch (Figs. 2 and 3). It is only due to the initial start which soil under artificial mulch acquires that there remains over a certain period more moisture under artificial mulch, otherwise soil mulch is more effective in conservation of moisture. It is therefore not

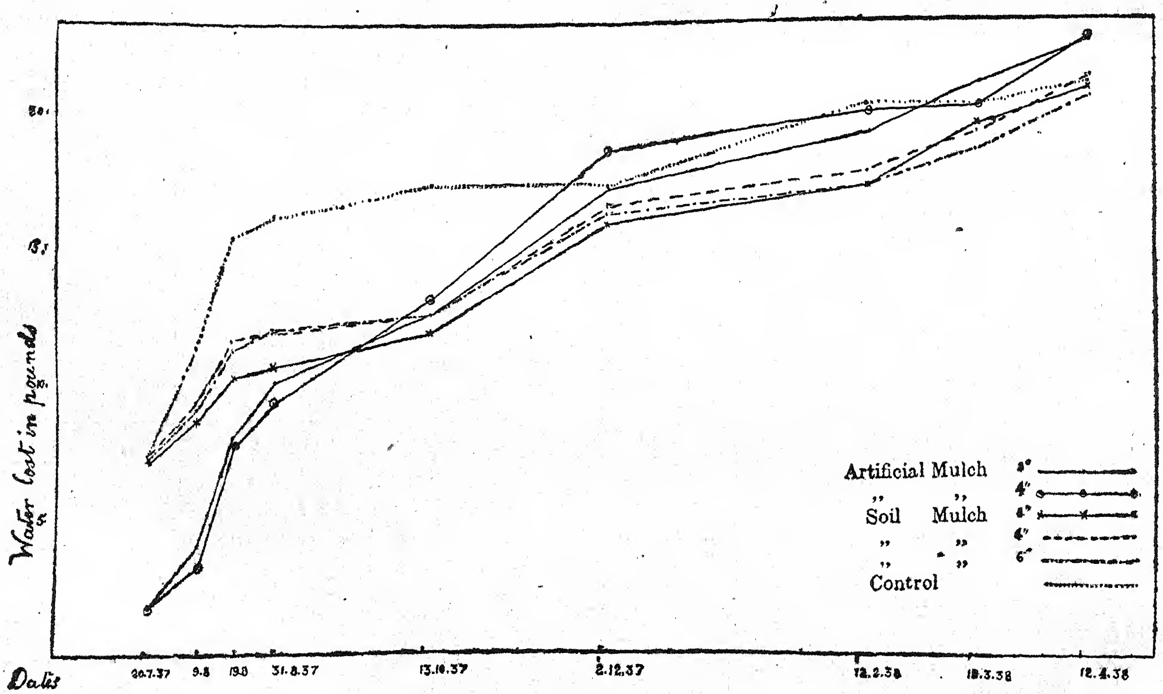

FIG. 2. Total loss of water from 20 July 1937

correct as maintained by workers like Harris and Jones [1918] that artificial mulches are more effective than soil mulch in the conservation of moisture. The obvious conclusion is that artificial mulch protects the soil from the heat of the sun, while soil mulch, in addition to it, also breaks the capillary connections and this slows down the upward movement of moisture.

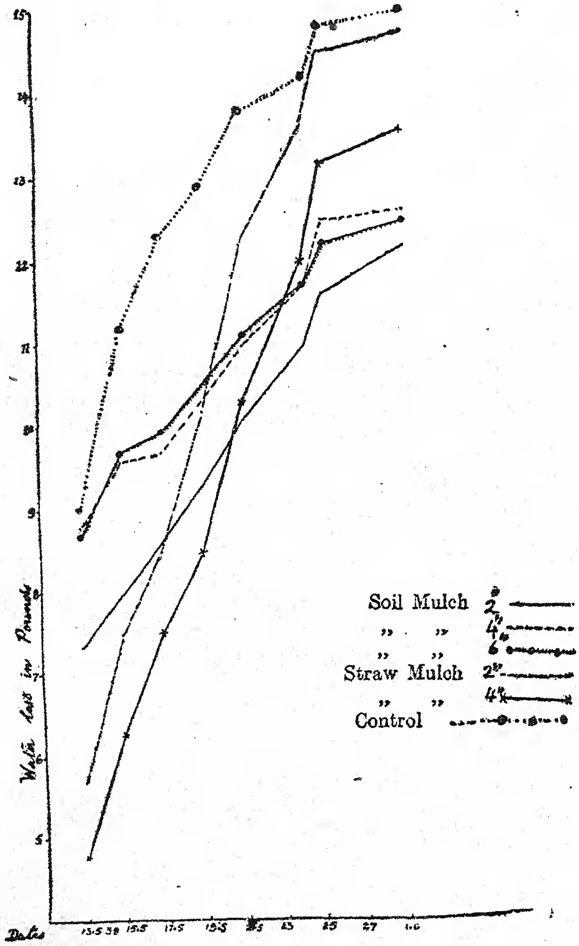

FIG. 3. Total amount of water from 13 May 1938

It is only for a certain period after the application of water that a soil under artificial mulch contains more moisture, and this period depends on the meteorological conditions. During summer when dry conditions prevail this period lasts from 20 to 30 days, that there is a significant difference. During winter when the temperatures are low and less dry conditions exist, differences are more, and remain for a longer period. From 19 July to 2 August in a period of 14 days there was a decrease of 8·70 and 7·83 per cent, and from 13 February to 4 March in a period of 19 days there was fall of 6·04 and 5·07 per cent of moisture from plots under artificial and soil mulch respectively. Unlike the observations of Russell [1940], the artificial mulch has been observed to retain more moisture than soil mulch even during rainless periods, but this duration will depend on the meteorological conditions.

Yield of the crop

Cotton crop was sown on 2 April 1940 and barley on 11 October 1941. After sowing of the crop artificial mulch was removed. The yields in pounds per acre of both the crops are given in Table X.

TABLE X

	Seed cotton	P	Barley grain	P
Artificial mulch .	1423	<0·05	160	>0·05
Soil mulch .	541	119	119	..

The normal time for the sowing of cotton is the month of April or May, but under dry farming conditions cotton cannot be sown during these months for want of rains. Therefore, it is sown at the end of June or the beginning of July when the monsoons break, but then it is very late. The crop sown so late yields very low as it is left with a small growing period. It was therefore decided to ascertain whether by the application of artificial mulches the moisture conserved due to winter rains could be carried to the month of April, and cotton sown in these plots could yield well. The results show that yields of cotton obtained from the plots under artificial mulch are much higher than those under soil mulch. Under dry farming rains close by the middle of September and the moisture is to be carried for sowing of winter crops to the last week of October or beginning of November. It has been observed that the crops sown late yield well. To find out the effect of late sowing in the artificial mulched plots barley was sown on 11 November 1941. The yield results show that there were 41 lb. more barley from the artificial mulched plots. The differences are not so great as in the case of cotton, but the results are in accordance with the moisture data reported. At the time of sowing cotton there was 2·11 per cent more moisture in a 3 ft.

column under artificial mulch than soil mulch. While at the time of sowing barley on 11 November 1941 there was no significant difference of moisture in the surface 2 ft. but in the third foot there was about 1 per cent more moisture in the plots under artificial mulch. It is probably due to this deep-seated moisture that slight increase in yields of barley was obtained from the artificial mulched plots.

As already reported, during summer it is only for a period of 25 to 30 days that there is more moisture in the artificial mulched plots. Therefore *rabi* crops (winter crops) in the plots under artificial mulch can only derive benefit if sown a month after the close of rains. In case the interval is longer the differences will be slight, and this will not lead to any advantage. However, in the winter season a crop can be sown with advantage a month or two after the close of winter rains.

Economic possibilities of artificial mulches

It may however be pointed out that the economic possibilities of artificial mulches have not been fully explored, as they are governed by many considerations of which the availability of waste plant material is an important factor. In the experiment reported cotton sticks were employed as artificial mulch, but it should be left to the expediency of zemindars to utilize whatever waste plant material is available to them in a particular locality. Cotton sticks are ordinarily used by the zemindars for fuel purposes, but the same use can be made even after they have secured the purpose of artificial mulch. The cost of spreading and removing should be quite nominal as the zemindar under dry farming conditions is not very busy and is not required to employ extra labour. However, for purposes of working out economics, the cost of spreading and removing may be reckoned at Rs. 7*. There may be slight loss of the material itself which may amount to Rs. 5. Income due to increase in yield of 882 lb. of seed cotton amounts to Rs. 53 resulting in net profit of Rs. 41.

The use of artificial mulches has been made for growing sugarcane under dry farming conditions by spreading the cane trash in between the rows. The extra moisture thus conserved, enables the sugarcane crop to withstand drought in years of scanty or unevenly distributed rainfall.

(On prewar basis)

	Rs.	A.
* Cost of carting 200 md. of cotton sticks required to cover one acre (wages of two labourers and rent of two carts)	5	0
Wages of two labourers for spreading of cotton sticks	1	0
Wages of two labourers for removing of cotton sticks	1	0
Price of 25 md. of cotton sticks lost during use @ -/3/- per md.	4	11
Total expenditure	11	11
Income due to 10 md. 31 sr. (882 lb.) of seed cotton at Rs. 5 per md.	53	9
Net profit	41	14

Summary and conclusions

The results of a study of the relative effect of artificial and soil mulches on the conservation of soil moisture has been presented.

1. There is more moisture under artificial mulch than soil mulch over a period of 20 to 60 days depending upon the seasonal conditions.
2. Soil mulch conserves moisture better than artificial mulch, but greater moisture under artificial mulch is due to the fact that 39 to 46 per cent of the moisture from the soil is lost before it can be cultivated to form soil mulch. After a soil mulch is formed losses from the soil mulched plots are less than from the artificial mulch plots.
3. There is more absorption of water in artificial mulch plots. When rain falls in small showers it does not increase the moisture of heavy type of soil.
4. Artificial mulch is more effective on a heavy type than on light type.
5. Effect of meteorological factors on the evaporation has been discussed. Artificial mulches are less effective during summer than during winter months.
6. Artificial mulch 2 in. deep and soil mulch 4 in. deep bring about maximum conservation of moisture.
7. Yields of cotton and barley from the artificial and soil mulch plots are given and the possibility of growing crops in the moisture conserved by artificial mulches has been discussed.

Acknowledgement

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A SIMPLE METHOD FOR ESTIMATING CARBONATES IN SOILS

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Several methods for the estimation of carbonates in soils have been proposed from time to time. Soil workers are familiar with the methods of Brown and Escombe [1900], Hall and Russell [1902], Amos [1905], Collins [1906], Marr [1908], Gaither [1912], Shrewsbury [1912], MacIntyre and Willis [1913 ; 1915], Hutchinson and MacLennan [1914], Truog [1916], Hardy [1921], Sanyal [1923], Underwood [1926], Clark and Collins [1929], Schollenberger [1930], and Puri [1930].

All the above methods require elaborate glass apparatus and involve complicated manipulations. They are, therefore, unsuitable for use in ordinary routine analysis, where a large number of estimations have to be made in a day. Hence there is a real need for a simple, rapid and fairly accurate method.

Puri [1930], working in these laboratories, developed a direct titrametric method. It offers no doubt certain advantages in point of simplicity and rapidity. It consists in titrating with $N/2$ H_2SO_4 a known weight of soil suspended in a saturated solution of $CaSO_4$ in the presence of 10 c.c. of $N/10$ Al_2Cl_6 solution and an equal amount of brom thymol blue and brom cresol green indicators with boiling after each addition of acid till the colour of the supernatant liquid is golden yellow. In several instances the results however differ considerably from those obtained by the gravimetric method.

This has been tested and found to give lower results than the gravimetric method. This is partly attributed to the acidity of 10 c.c. of $N/10$ Al_2Cl_6 solution equivalent to 2 c.c. of $N/2$ H_2SO_4 not being taken into account by Puri and partly to the fact that the amount of acid used is not enough to completely decompose the soil carbonates.

The gravimetric method employed in this laboratory for comparative tests consists in boiling the soil with about 50 c.c. of normal HCl (1 : 10) at atmospheric pressure for 5 min. The CO_2 evolved is first led through a condenser which retains back the HCl fumes, then dried by passing through U-tubes containing strong H_2SO_4 soaked in pumice and next collected in soda lime U-tubes. After the boiling is over, about a litre of CO_2-free air is aspirated for half an hour to sweep away all the evolved CO_2 from the reaction flask. There are guard tubes containing H_2SO_4 soaked in pumice attached to the further end of the soda lime tubes to retain any moisture that may enter the apparatus by back suction. This method has been found to yield satisfactory results with most Indian soils which are usually poor in organic matter.

TABLE I

Comparison of values for CO_2 by gravimetric and Puri's titrametric methods

Serial No.	Locality of soil samples	Per cent CO_2		
		Gravimetric method	Puri method	Difference
1	Nagpur, Central Provinces	0·82	0·30	—0·52
2	Dholkapaldi, Bombay (Good)	0·89	0·22	—0·67
3	Dholkapaldi, Bombay (Bad)	2·86	2·15	—0·71
4	Delhi, Depth 13—14 ft.	2·69	1·56	—1·13
5	Delhi, Depth 4 ft. 4 in.—6 ft. 4 in.	6·65	5·42	—1·23
6	Bannu, N.-W.F. Province	6·47	5·60	—0·87
7	Pusa, Bihar . . .	15·78	14·53	—1·25
8	Akola, Central Provinces	3·21	2·33	—0·88
9	Coimbatore, Madras .	1·15	0·62	—0·53

From Table I it is evident that the CO_2 values by the Puri method are considerably lower than those obtained by the gravimetric method. If an allowance is made for the acidity of the 10 c.c. of $N/10$ Al_2Cl_6 solution used in the Puri method, the CO_2 values become higher by about 0·44 per cent in every case, but are still lower than the CO_2 values by the gravimetric method. This is due to the amount of acid used being not enough to completely decompose the soil carbonates. A slight excess of acid is essential to completely decompose the soil carbonates, as will be shown in the sequel. If the calculations were made as $CaCO_3$, the differences between the values by the two methods would be about 2½ times higher than those given above.

Detailed account of the proposed method. Depending on the approximate amount of carbonates present in a soil as judged qualitatively by the strength of effervescence on decomposing a little of the soil with dilute acid, two 1 to 10 gm. portions of the soil sample are exactly weighed out in two 500 c.c. conical flasks, to each of which are added 50 c.c. of distilled water and a measured quantity of half normal hydrochloric acid in slight excess (about 4 to 5 c.c.) of what is actually required to completely decompose the soil carbonates.

The contents of one of these flasks are then slowly boiled for 5 min. on wire-gauze over a small flame. The excess acid is finally titrated back with deci-normal caustic soda using phenolphthalein as indicator.

The contents of the second flask are shaken from time to time for half an hour in the cold at room temperature, and then the excess acid is titrated back as in the first case.

The titre figures are quite reproducible and the end-point is very sharp. The alkali used is converted into half-normal strength by dividing the titre figure by five. The quotient thus obtained is subtracted from the c.c.s of $N/2$ HCl taken and the resultant figure gives the amount of acid consumed to decompose the soil carbonates present in the sample taken for analysis. One c.c. of $N/2$ HCl corresponds to 0·011 gm. CO_2 or 0·025 gm. $CaCO_3$. The values for CO_2 obtained by either boiling or shaking in the cold are fairly concordant, and, therefore, the mean of these two values has been taken for comparing with the CO_2 values obtained by the gravimetric method.

The effect of time of boiling, or shaking in the cold at room temperature on the reaction between acid and soil carbonates is seen from the following results. Two grams of a Delhi soil having 6·65 per cent of CO_2 were treated with 50 c.c. of water and 17 c.c. of $N/2$ HCl which included about 5 c.c. of $N/2$ HCl in excess of what is actually required to completely decompose the soil carbonates.

TABLE II

Effect of time of shaking in the cold or boiling on the reaction between acid and soil carbonates

Minutes shaken	Per cent CO_2	Minutes boiled	Per cent CO_2
5	5·91	1	6 44
10	6·05	2	6 40
15	6·24	3	6·55
20	6·30	4	6·56
25	6·38	5	6·66
30	6·68	7	6·63
45	6·69	10	6·66
60	6·73	15	6·62

It is evident that either shaking at room temperature for 30 min. or boiling for 5 min. in the presence of slight excess of acid gives the most satisfactory values for CO_2 comparable with that given by the gravimetric method. It is necessary that a definite excess of acid should

be maintained to completely decompose the soil carbonates under the conditions of the experiment. This excess of $N/2$ HCl is diluted in the presence of 50 c.c. of water to about $N/25$ strength which is too dilute to have any appreciable action on the organic matter or soil bases. This will be evident from the data given in Tables III and IV.

A number of typical soils from different parts of India have been examined by the new method and the results compared with those by the gravimetric method in Table III.

TABLE III

Comparison of the values for CO_2 by N/2 HCl method and the gravimetric method

Serial No.	Locality of soils	Characteristics	Per cent CO_2 — $N/2$ HCl method: Boiled 5 min.	Shaken 30 min.	Mean	Gravimetric method
1	Delhi	Alluvium depth 5-6 ft.	6·21	6·46	6·34	6·51
2	,,	,, ,, 4 ft. 4 in.-6 ft. 4 in.	6·54	6·62	6·58	6·65
3	,,	,, ,, 14-15 ft.	2·50	2·64	2·62	2·69
4	,,	,, ,, 0-1 ft.	0·04	0·04	0·04	0·01
5	,,	,, ,, 1-2 ft.	0·04	0·06	0·05	0·04
6	,,	,, ,, 2-3 ft.	0·04	0·04	0·04	nil
7	,,	,, ,, 3-4 ft.	0·03	0·05	0·04	0·05
		North-west Frontier Province				
8	Bannu	Alluvium depth	6·43	6·48	6·46	6·47
9	Taru Jabba	,, ,,	7·58	7·69	7·64	8·61
10	Peshawar	,, Wheat Land	7·03	6·81	6·92	7·00
11	,,	,, Grass ,,	6·87	6·81	6·84	6·86
12	,,	,, Kallar (alkali) efflorescence	6·05	6·05	6·05	6·25
		Sind				
13	Sukkur	Good alkali soil	5·59	5·33	5·46	5·47
14	,,	Bad ,, ,,	5·03	4·78	4·91	4·76
		Bombay				
15	Poona	Daccan trap	2·80	2·80	2·80	2·77
16	Dholkapaldi	Alluvium good soil	0·86	0·88	0·87	0·89
17	,,	,, bad ,,	2·60	2·60	2·69	2·80
18	Dharmuj	Alluvium	0·66	0·68	0·67	0·69
19	Nadiad	,,	0·79	0·80	0·80	0·76
		Central Provinces				
20	Nagpur	Black soil	0·77	0·79	0·78	0·82
21	Akola	Black cotton soil	2·91	3·13	3·02	3·14
		Punjab				
22	Lyallpur	Alluvium	0·66	0·66	0·66	0·66
23	Gujranwalla	,,	0·40	0·42	0·41	0·41
24	Solon	Hill soil	1·14	0·92	1·03	1·04
25	Simla	,, ,,	nil	nil	nil	nil

TABLE III—*contd*

Serial No.	Locality of soils	Characteristics	Per cent CO_2			
			N/2 HCl method			Gravimetric method
			Boiled 5 min.	Shaken 30 min.	Mean	
		United Provinces				
26	Saharanpur	Alluvium	nil	nil	nil	nil
27	Cawnpore	,,	0·22	0·18	0·20	0·19
		Bihar				
28	Pusa	Alluvium calcareous	15·40	15·40	15·40	15·78
29	Sepaya	,, ,, 12-18 in.	3·36	3·30	3·33	3·33
30	Gaya	Alluvium	1·76	1·76	1·76	1·70
31	Ranchi	Laterite acid	nil	nil	nil	0.04
32	Banka	,, ,,	nil	nil	nil	nil
		Orissa				
33	Cuttack	Laterite acid	nil	nil	nil	nil
34	Balasore	,, ,,	nil	nil	nil	nil
		Bengal				
35	Dacca	Laterite acid $pH=3.92$	nil	nil	nil	0·04
36	Darjeeling	Acid. Tea soil	nil	nil	nil	0·06
		Assam				
37	Karimganj	Acid $pH=5·0$	nil	nil	nil	0·05
38	Jorhat	,, $pH=4·6$	nil	nil	nil	0·04
		Burma				
39	Mandalay	Acid $pH=4·0$	nil	nil	nil	0·04
		Madras				
40	Coimbatore	Brown soil	1·10	1·13	1·12	1·15
41	Bangalore	Red soil	0·04	0·06	0·05	0·06
42	Guntur	Black soil	1·05	1·05	1·05	1·05
43	Coorg	Acid organic soil $pH=5·0$, 15 per cent loss on ignition	nil	nil	nil	0·40
44	Coorg	Acid organic soil $pH=5·0$, 9 per cent loss on ignition	nil	nil	nil	0·37
45	Coorg	Acid organic soil $pH=5·0$, 8 per cent loss on ignition	nil	nil	nil	0·30

It is seen that the new method is applicable to all the Indian soils tried and gives results closely agreeing with those obtained by the gravimetric method except in the case of the few Coorg soils which are rather rich in organic matter. The latter soils are acid having a pH of 5·0 and are therefore not expected to contain any native carbonate as indicated by the gravimetric method. They as well as the other acid soils examined give off no CO_2 by the new method, which thus gives a true picture of the carbonate status of soils in general.

The effect of such substances as salts, oxides, and silicates on the results by the new method is hardly appreciable as can be seen from the results in Table IV. To two-gram portions of a soil was introduced 0·2 to 0·3 gm. of different oxides, salts, and silicates which amounted to

10 to 15 per cent of the soil taken. With 50 c.c. of water and 16 c.c. of $N/2$ HCl which included 4 c.c. of $N/2$ HCl in excess, the contents were boiled for 5 min., after which the excess acid was determined as usual.

TABLE IV

Effect of different oxides, salts, and silicates on the N/2 HCl method for estimating soil carbonates

Serial No.	Impurities added	Per cent CO_2 found	Difference from control
1	Control. Soil alone	6·47	—
2	Sodium chloride	6·51	+0·04
3	,, nitrate	6·47	nil
4	,, sulphate	6·43	—0·04
5	Potassium chloride	6·55	+0·08
6	Calcium chloride	6·56	+0·09
7	Magnesium chloride	6·47	nil
8	10 c.c. N/10 aluminium chloride*	6·43	—0·04
9	Aluminium oxide**	6·46	—0·01
10	Ferric Oxide	6·55	+0·08
11	Titanium oxide	6·40	—0·07
12	Manganese dioxide	6·46	—0·01
13	Silica**	6·47	nil
14	Talc	6·54	+0·07
15	Kaolin	6·55	+0·08
16	Fuller's Earth	6·55	+0·08

* The acidity of aluminium chloride solution used was equivalent to 2 c.c. of $N/2$ HCl for which due allowance was made.

** Alumina and silica were alkaline requiring respectively 0·4 c.c. and 0·2 c.c. of $N/2$ HCl for neutralisation and due allowance was made for this.

The proposed method requires a minimum of glass apparatus which is easily available in any laboratory, and the manipulations involved in its working are very simple and can be quickly carried out. It offers advantages in point of simplicity and rapidity over the other methods. The simplicity and the degree of accuracy mark out the method as being most useful to soil workers, especially those engaged in soil survey work.

SUMMARY AND CONCLUSIONS

A simple and rapid method for estimating carbonates in soil has been outlined. It consists in either boiling for 5 min. or agitating at intervals for half an hour at room temperature a known weight of a soil with a measured quantity of $N/2$ HCl in slight excess (4 to 5 c.c.) of what is actually required to completely decompose the soil carbonates and 50 c.c. of water in a 500 c.c. conical flask and then titrating back the excess acid with decinormal caustic soda using phenolphthalein as indicator. The end-point is sharp and the titre figures are reproducible.

The method has been tested with a variety of soil types available in India and has proved to be of sufficient accuracy to warrant its employment in routine soil analysis, or on the field where a large number of samples have to be quickly tested.

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PLANT QUARANTINE NOTIFICATION

Notice No. 2 of 1944

THE following quarantine regulations have been received in the Imperial Council of Agricultural Research. Those interested are advised to apply to the Secretary, Imperial Council of Agricultural Research, New Delhi.

1. Japanese Beetle quarantine—(Quarantine No. 48), and
2. Pink Bollworm quarantine—(Quarantine No. 52)

Issued by the Department of Agricultural, United States of America.

ERRATA

The Indian Journal of Agricultural Science Vol. XIV, Part I, February 1944

Page 49, line 22 (1st col.), *for* ' USTILAGO ANDROPOGONIS-FINITIM ' *read* ' USTILAGO ANDROPOGONIS-FINITIMI '

Page 50, line 11 from bottom (1st col.), *for* ' CINTRACTIA DISVANS ' *read* ' CINTRACTIA DISTANS '

Page 52, line 10 from bottom (2nd col.), *for* ' of smuts hitherto unrecorded for India ' *read* ' of smuts, of which 17 were hitherto unrecorded for India '

MGIPC—M—III-1-37—23-4-45—600.

ORIGINAL ARTICLES

PHOTO-HYDROLYSIS OF STARCH

By M. R. Madhok and Fazal Uddin, Bacteriological Research Laboratories, Punjab Agricultural College, Lyallpur

(Received for publication on 17 June 1944)

Hydrolysis of starch by the action of enzymes and acids is a well-known phenomenon. Biedermann in his series of publications [1919-1924] reported that certain neutral salts such as potassium phosphate, sodium chloride, etc. could also hydrolyse starch. He further found that a mixture of sodium chloride, potassium phosphate and glycine was capable of hydrolysing a 1 per cent solution of starch in two hours.

A number of workers like Bachrach [1921], Bokorny [1921], Teschendorf [1921], Rothlin [1922] could not, however, confirm his results and attributed the observed hydrolysis to either the contamination of starch with amylase or to bacterial action. Other workers, like Haehn [1924] and Iljin [1924], confirmed Beidermann's findings.

During our investigations on the losses of nitrogen from sodium nitrite in the presence of starch, it was incidentally noted that starch disappeared completely from flasks which were exposed to the sun for sometime. On the other hand, flasks kept in the dark continued to give a positive reaction for starch. Besides a slight reduction and oxidation, denitrification of sodium nitrite was also observed in the presence of light.

(A). So far as the transformation of starch is concerned the foregoing experiment was only of a qualitative nature. That starch disappeared in the presence of sunlight was quite obvious, but it remained to be seen whether starch in the unexposed flasks had undergone any transformation. Another experiment was therefore conducted with 0·5 per cent starch solution. Determination of starch was made after five weeks duration by the starch iodide gravimetric method.

The results given in Table I showed that starch is not hydrolysed in the dark even in the presence of sodium nitrite and the change is entirely a photo-chemical one. The sterility of the solution in the flasks was tested before analysis.

Table I

Starch in gm. per 100 c.c. solution

Exposed	Un-exposed	
	With nitrite	Without nitrite
Nil	0·48	0·51
Nil	0·50	0·50

A number of experiments on various aspects of the subject were then conducted. The technique followed and the material used throughout, except where otherwise mentioned, were as follows :

Soluble starch (May and Baker) was used in all the experiments. The solution was exposed in Pyrex glass rimless culture tubes measuring 6 in.×0·5 in. Paper was always tied over the plugs to protect them from dust. Ten c.c. of 0·1 per cent starch solution were put in the tubes. Sterilization was done in the autoclave at 15 lb. pressure for half an hour. Sodium nitrite was used in 0·2 per cent concentration as a catalyst and its solution was sterilized separately and added aseptically when required.

(B). Since nitrite in the presence of starch undergoes both reduction and oxidation, experiments were conducted to determine the extent to which the three ions, viz. NH_4, NO_3 and NO_2 catalyse the reaction. For this purpose, solutions of sodium nitrite, sodium nitrate and ammonium sulphate were prepared on equal nitrogen basis, sterilized and used as catalysts.

The results obtained showed that in the presence of sodium nitrite starch disappeared in about a week's time, while in the presence of sodium nitrate it took over four weeks. In the presence of ammonium sulphate a positive reaction for starch was obtained even after a lapse of many weeks.

It is likely that the destruction of starch in the case of sodium nitrate may be due partly or entirely to the presence of NO_2 ions produced as a result of the photo-reduction of nitrate, but it is not clear from the results of the above experiment as to how far this is due to the presence of one or the other ion (NO_2 or NO_3) or to the combined action of both. However, even if NO_3 ions catalyse this reaction, their effect seems to be much slower.

(C). An experiment was conducted to ascertain if dextrin can be hydrolysed in the presence of sodium nitrite. For this purpose a 0·2 per cent solution of dextrin was used. The results obtained showed that dextrin completely disappeared in 10 days in the exposed tubes treated with sodium nitrite while the unexposed tubes continued to give a positive test up to the end of six weeks, when the experiment terminated.

Qualitative tests carried out to detect the disappearance of starch in the preliminary experiments often gave a reddish brown colouration with iodine solution in the exposed tubes indicating the presence of dextrin in the solution. Other tests, the alcohol and basic lead acetate tests, also showed its presence when 0·5 per cent starch solution was tested after the disappearance of starch. The solution when free from starch and dextrin (as shown by the iodine test) was also found to reduce Fehling's solution showing thereby the presence of reducing sugars. The reducing power of a 0·2 per cent starch solution was found to be equivalent to 0·08 per cent solution of glucose.

As the starch is first converted into dextrin and then into reducing sugars, evidently this is a case of hydrolysis. In order to study the effect of various factors on this reaction, the following experiments were undertaken:

Reaction of the solution

In order to determine the effect of reaction on the rate of hydrolysis of starch, the experiment was conducted at a pH of 5·2 and 8·6. The rate of hydrolysis was found to be the same at both the pH values. The pH of the tubes was again determined at the end of the experiment and was found to be practically the same as at the beginning.

The pH was adjusted by the addition of $N/10$ HCl or $N/10$ NaOH and both these reagents were found to have no action on the hydrolysis of starch in the absence of sodium nitrite.

Concentration of the catalyst

Four concentrations, viz. 1·0, 0·2, 0·04 and 0·008 per cent of sodium nitrite were tried. The rate of hydrolysis of starch was found to be practically the same in all concentrations from 0·04 to 1·0 per cent. With a 0·008 per cent concentration of the nitrite it was, however, found to be definitely lower.

Rate of hydrolysis of different starches

An experiment was conducted to compare the rate of hydrolysis of some different starches. The results given in Table II show that the rate of hydrolysis varies in different cases. Potato and soluble starch are more readily hydrolysed as compared to other starches from wheat, maize, rice, etc.

Table II

Starch	After 7 days		After 11 days		After 28 days		After 48 days	
	Starch	Dextrin	Starch	Dextrin	Starch	Dextrin	Starch	Dextrin
Buck wheat	+		trace	+	—	—	—	—
Sol. starch	—	+	—	trace	—	—	—	—
Potato	—	+	—	trace	—	—	—	—
Wheat	+		+		trace	+	—	—
Maize	+		+		trace	+	—	—
Rice	+		+		trace	+	—	—

Wave length of light

The experiment was conducted in usual way in culture tubes, which were kept immersed in clear water or coloured violet or red and then exposed to the sun. As expected the shorter waves were found to be more effective than the longer waves.

Influence of different compounds

(*a*) In order to determine the effect of other sodium salts on the hydrolysis of starch, a series of trials were conducted as usual with sodium acetate, borate, carbonate, phosphate, tartarate and chloride. The concentration of the starch solution and of the catalyst used in each case was 0·1 and 1·0 per cent respectively. The experiment lasted for two months. The results were negative in every case, i.e. disappearance of starch was not noted in any case.

(*b*) Other substances like mercuric oxide, bismuth oxide, zinc oxide, reduced nickel and animal charcoal were also tried as catalysts. The oxides were washed free of any traces of NO_2 before use. A 0·1 gm. of the catalyst was added to each tube. After sterilization the cotton wool

plugs were replaced by sterilized tight-fitting corks. This was considered necessary in order to keep off atmospheric ammonia which gets oxidized to nitrite in the presence of oxidizing photo-catalysts. The experiment lasted for four weeks. It was found that zinc oxide acted catalytically on the hydrolysis of starch. The rate of hydrolysis appeared to be the same as with sodium nitrite. Mercuric oxide acted positively but the action was rather weak.

(c) Another experiment was conducted to verify the claims of Biedermann [1919-1924] that a mixture of glycine, potassium phosphate and sodium chloride hydrolysed starch in two hours. As the original article by Biedermann was not available, the trial was conducted as follows:

A 0·1 per cent starch solution was prepared with 0·2 per cent each of potassium phosphate, sodium chloride and glycine.

It was tubed in 10 c.c. portions and sterilized. Some tubes were exposed to the sun and the others were kept in the dark. Occasional tests with iodine solution up to a period of six weeks did not show the disappearance of starch.

Summary

1. Starch undergoes hydrolysis under the action of light in the presence of catalysts.

2. Shorter waves of light are more active in their effect than the longer waves.

3. Sodium nitrite, zinc oxide and mercuric oxide act as catalysts for the hydrolysis of starch.

4. The rate of hydrolysis varies with different starches.

5. The rate of hydrolysis is unaffected between the pH range 5·2-8·6.

6. A mixture of potassium phosphate, sodium chloride and glycine did not catalyse the hydrolysis of starch as observed by Biedermann.

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STUDIES ON THE ROOT-ROT DISEASES OF COTTON IN THE PUNJAB

XIII. LEAF TEMPERATURES OF HEALTHY AND ROOT-ROT AFFECTED PLANTS

By R. Sahai Vasudeva, Ph.D. (Lond.), D.I.C. (Lond.), Assistant Plant Pathologist, Imperial Agricultural Research Institute, New Delhi

(Received for publication on 8 May 1944)

Root-rot disease of cotton is the most serious disease of this crop in the Punjab and causes heavy damage to the crop every year [Vasudeva, 1935]. In a freshly wilted plant excepting a few roots which hold the plant in position, most of the other roots are decayed and bark broken down into shreds. The food supply of the plants is thus cut off and the plants are killed out right within a very short period. The disease actually starts much earlier, and the above-ground manifestation of the disease in the form of wilting is a very late symptom.

In the course of some field experiments in which the cotton plants attacked by root-rot were under study it was observed that the leaves of the affected plants have decidedly a higher temperature. The experimental data are recorded in this paper and it may later on be possible to use leaf temperature as an index for the identification of plants affected by root-rot disease. The experiments though have no direct bearing on the problem are nevertheless cognate to the subject and are included in this series.

Experimental

The temperature of the leaves was recorded by the thermo-electric method. The apparatus employed consisted of constantan wire, copper

wire, a unipivot galvanometer, a spring key and centigrade thermometers. The ends of the constantan wire were soldered with the ends of the two copper wires; the absorption coefficient of these wires being nil. The free ends of the copper wires were connected to the galvanometer and the spring key respectively. The key and the galvanometer were connected by a similar piece of copper wire. All the wires were carefully insulated with rubber valve-tubing. A galvanometer sensitive enough to indicate at least 0·0025 micro-amperes was used.

Of the two thermo junctions one was placed in a Dewar's flask containing cold water along with a thermometer and served as the 'cold juction'. In order to guard against the sudden fluctuations in air temperature, the Dewar's flask was kept in a wooden box containing sawdust. The temperature of the water in the flask was kept constant at about 10°C. In measuring the temperature, the leaf was folded upwards in such a way that two portions of the upper surface were brought firmly together over the free juction by means of a pair of tongs, the tips of which had been previously covered with pieces of cork. The circuit was then completed by inserting the key. The deflection caused by the difference of temperature of the two junctions was recorded. The internal temperature of the leaves was determined by inserting the free junction in the tissue of the mid-rib. The corresponding temperature of air was recorded by holding the free junction in air and necessary precautions to protect it from the direct rays of the sun were taken. Two cotton plants of variety *Gossypium indicum* (15 Mollisoni) standing in the same field, of the same age and as far as possible of the same size were selected early in the morning every day: One which just showed the first apparent signs of wilting, i.e. slight drooping of top-most leaf, and the other which appeared perfectly normal and healthy. The leaf temperature was measured four times during the day, i.e. at 6·30 a.m., 9 a.m., 12 noon and 5 p.m. Temperatures of six leaves were determined on each plant at one time; the readings for the temperature determinations of healthy leaves alternating with those of the diseased ones. Corresponding temperature of air at that particular time was also recorded. Leaves which faced the sun at right angles were always selected so that the results could be strictly comparable.

The leaf temperatures were recorded during a number of days on different pairs of healthy and diseased plants during July and August. Determinations of the leaf surface and inner tissue temperatures were made simultaneously. Data for a single pair of plants are recorded in Table I.

TABLE I

Leaf temperatures of a healthy and a diseased cotton plant at different times of the day

Time	Temperature of air °C.	Temperature of old junction °C.	No. of deflections of the galvanometer			Calculated temperature			Healthy or diseased	Value of *t*	
			Air	Upper surface	Inner tissue	Air	Upper surface	Inner tissue		Upper surface	Inner tissue
6.30 a.m.	29·4	23·4	21	25	25	29·4	30·52	30·52	H		
				27	27		31·09	31·09	D		
	29·6	23·4	27	25	24	29·6	29·12	28·89	H		
				28	28		29·86	29·80	D		
	29·8	23·4	26	27	27	29·8	30·04	30·04	H		
				30	30		30·73	30·73	D	4·17	4·10
	30·0	23·4	28	28	28	30·0	30·00	30·00	H		
				30	30		30·47	30·47	D		
	30·2	23·4	28	28	28	30·2	30·20	30·20	H		
				35	35		31·90	31·90	D		
	30·4	23·4	29	29	27	30·4	30·40	29·92	H		
				36	35		32·09	31·85	D		

TABLE I—*contd.*

Time	Temperature of air °C.	Temperature of old junction °C.	No. of deflections of the galvanometer			Calculated temperature			Healthy or diseased	Value of t	
			Air	Upper surface	Inner tissue	Air	Upper surface	Inner tissue		Upper surface	Inner tissue
9.0 a.m.	34·0	24·8	35	38	31	34·0	34·79	32·95	H		
				46	43		36·89	36·10	D		
	34·0	24·8	35	40	33	34·0	35·31	33·50	H		
				47	43		37·15	36·10	D		
	34·0	24·8	35	38	34	34·0	34·79	33·73	H		
				48	43		37·41	36·10	D		
	34·2	24·8	35	37	34	34·2	34·73	33·93	H	7·85	7·55
				50	40		38·32	35·54	D		
	34·4	24·8	36	39	37	34·4	35·20	36·66	H		
				54	44		39·20	36·53	D		
	34·4	24·8	38	42	38	34·4	35·41	34·40	H		
				51	43		37·68	35·66	D		
12.0 Noon	38·4	25·4	44	49	42	38·4	39·87	37·81	H		
				56	47		41·94	39·28	D		
	38·4	25·4	46	47	43	38·4	38·68	37·55	H		
				55	46		40·94	38·40	D		
	38·6	25·4	45	48	43	38·6	39·48	38·01	H		
				60	52		43·00	40·65	D		
	38·6	25·4	43	49	44	38·6	40·44	38·95	H	15·73	4·63
				59	53		43·51	41·67	D		
	38·8	25·4	44	49	43	38·8	40·32	38·50	H		
				59	51		43·36	40·93	D		
	38·8	25·4	44	48	44	38·8	40·21	38·50	H		
				57	45		42·76	39·10	D		
5.0 p.m.	38·4	28·8	44	46	43	38·4	38·83	38·18	H		
				55	46		40·80	38·83	D		
	38·4	28·8	43	44	41	38·4	38·62	37·95	H		
				54	48		40·85	39·51	D		
	38·4	28·8	41	38	34	38·4	37·69	36·76	H		
				48	40		40·04	38·16	D		
	38·4	28·8	42	33	30	38·4	36·34	35·65	H	12·38	4·78
				44	40		38·86	37·04	D		
	38·4	28·8	39	36	32	38·4	37·66	36·67	H		
				47	37		40·37	37·90	D		
	38·4	28·8	39	39	36	38·4	38·40	37·66	H		
				45	38		39·88	38·15	D		

It is observed that diseased plants remain considerably warmer as compared with the healthy ones. To show the statistical significance of the differences in temperature recorded, a function t was calculated from the data as described by Fisher [1924]. For a series of six observations the value of t 2·57 is just on the margin of significance. (The usual 20 : 1 standard being

adopted). The temperature differences both of upper surface and inner tissue of the diseased and healthy leaves are found to be significant. The inner tissue temperature shows a constantly lower value than the surface temperature and this holds good in the healthy as well as in the diseased plants. The value of t for the comparisons as shown in Table I is extremely high. This represents enormously great probability that the temperature of the leaves of a diseased plant is higher than that of the leaves of a healthy plant. The same type of experiments were repeated using different pairs of plants with similar results.

All the comparisons shown above are clearly significant and are in accordance with the observations of Ezekiel and Taubenhaus [1932] for *Phymatotrichum* root-rot and with Luthra and Chima [1937] who brought about wilting of the cotton plants by withholding the water supply.

Preliminary experiments conducted to determine the rate of transpiration of healthy and root-rot affected cotton plants showed that the rate of transpiration is considerably higher in healthy plants. The increase in temperature of root-rot affected plants is probably due to the defective root absorption as a result of which the moisture supply of the leaves is curtailed and the heat incident on the leaves is not dissipated resulting in the warming up of the leaves. On the other hand, in healthy plants the transpiration is fairly active and consequently the leaves remain comparatively cool.

The observations recorded were made during the course of the investigation of root-rot disease of cotton in the Punjab financed by the Indian Central Cotton Committee to whom my thanks are due.

Thanks are also due to Mr Inder Singh Chima of the Botanical Section, Agricultural College, Lyallpur, for his assistance.

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STUDIES ON THE ROOT-ROT OF COTTON IN SIND

II. RELATION OF ROOT-ROT OF COTTON WITH ROOT-ROT OF OTHER CROPS

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(Received for publication on 28 February 1944)

It has been observed that in addition to cotton, certain other crops suffer every year from root-rot. The crops most commonly attacked are castor (*Ricinus communis* L.), sesamum (*Sesamum orientale* L.), sunn-hemp (*Crotalaria juncea* Coso.), and *guar* (*Cyamopsis psoraloides* D. C.). Of all these sesamum and *guar* are the most affected.

The symptoms in all cases are similar to that of root-rot of cotton. The affected plants wilt suddenly. On pulling out the plants, it is seen that most of the lateral roots become fibrous, a yellow liquid oozes out on squeezing them and the roots ultimately rot. All the above-mentioned crops are cultivated during the summer months and root-rot is active from the beginning of June right up to the end of October.

Vasudeva [1935] also reports that root-rot affects several crops in the Punjab and that the causal organism is probably the same in all cases, i.e. *Rhizoctonia bataticola* (Taub.) (Butl.). In Sind the root-rot of cotton is caused by two fungi *Rhizoctonia bataticola* (Taub.) Butl. and *Fusarium coeruleum* (Lib.) Sacc. Both cause the disease either singly or together. This investigation was undertaken to find out whether the cause of the disease in different crops mentioned above is the same in Sind.

Material and methods

Rot-affected roots of castor, sunn-hemp, *til* (sesame) and *guar* were collected at different times from different places. Isolations from them were made at regular intervals. For isolation of the causal organisms (1) the mercuric chloride-sterile water, and (2) silver nitrate-sodium chloride methods were used. Numerous types of fungi were obtained in isolations from each crop.

Fungi like *Pennicilium* were not taken into consideration, and others were grouped together, to avoid handling a large number of isolates. The basis of grouping them together was the same as in the case of cotton, i.e. discolouration of the medium, presence or absence of aerial mycelium and spore-bearing structures.

TABLE I

Types of fungi isolated from different crops

Type No.	Aerial mycelium	Discolouration of medium	Spore bearing structures
1	Whitish fluffy	Light brown	None
2	Pinkish	Pink	None
3	None	None	Abundant sclerotia
4	Scanty whitish	Dark brown	Abundant sclerotia
5	White	Dark brown	Abundant sclerotia
6	Dirty white	Black	Abundant sclerotia
7	Buff	Brown	Pinnotes present

It was found that isolates No. 1 and No. 3 appeared most frequently and that they were *Fusarium* and *Rhizoctonia*, respectively. Both of them were selected for carrying out further infection experiments.

INFECTION TESTS

Experiment I

Inoculum was prepared in the usual way by growing cultures of *Rhizoctonia* isolated from each crop on soil and wheat flour. The seeds of various crops were sown in pots containing sterilized soil, and in between the two layers of inoculum, 12 seeds were sown in each pot.

The seedlings emerged from the soil 10 days after sowing. Twenty-five days later wilting was observed. The experiment terminated on 20 June 1941 and the final figures are given in Table II.

TABLE II

Germination and rotting with isolates of Rhizoctonia *from different crops*

Type of isolate	Crops	Total No. of seedlings	No. of seedlings which rotted	Germination percentage	Rotting percentage
Isolate from cotton	Cotton	31	13	64·5	41·9
	Castor	33	18	68·7	54·5
	Sunn-hemp	40	21	83·3	52·5
	Guar	43	26	79·5	60·4
	Til	45	27	93·7	60·0
Isolate from castor	Cotton	29	16	60·4	55·1
	Sunn-hemp	27	12	56·2	44·4
	Guar	37	10	77·0	27·0
	Castor	35	19	72·9	54·2
	Til	39	16	81·2	41·0
Isolate from sunn-hemp	Cotton	32	17	66·6	53·1
	Castor	41	22	85·4	53·6
	Sunn-hemp	36	15	75·0	41·6
	Guar	35	21	72·9	60·0
	Til	43	31	79·5	72·0
Isolate from *guar*	Cotton	29	16	60·4	55·1
	Castor	29	13	60·4	44·8
	Sunn-hemp	31	17	64·5	54·8
	Guar	33	21	68·7	63·6
	Til	37	15	77·0	40·5
Isolate from *til*	Cotton	34	13	70·8	38·2
	Castor	37	21	77·0	56·7
	Sunn-hemp	32	17	66·6	53·1
	Guar	35	16	72·9	45·7
	Til	42	22	87·5	52·3

Isolations were made from one of each series and the cultures so obtained were compared with cultures with which they were infected. Practically in all the cases they were found to be the same. Thus it is quite clear from Table II that rotting in case of all the crops is caused by *Rhizoctonia* and the fungus isolated from the rotted roots is pathologically the same. The results obtained in this experiment were confirmed.

Experiment II

Similar experiment was carried out with *Fusarium* isolated from the rotted roots of the above-mentioned crops. Inoculum was prepared in the usual way and pots were infected as described above. Twelve seeds were sown in each pot.

The seeds germinated 10 days after sowing and first wilting appeared 29 days after germination. This experiment terminated on 25 September 1941. The results of the experiment are given in Table III.

TABLE III

Germination and rotting percentage with isolates of Fusarium *from the affected roots of various crops*

Type of isolate	Crops	Total No. of seedlings	No. of seedlings which eventually rotted	Germination percentage	Rotting percentage
Isolate from cotton	Cotton	25	7	52·0	28·0
	Castor	23	8	47·9	34·7
	Sunn-hemp	27	6	56·2	33·3
	Guar	30	15	62·5	50·0
	Til	45	25	93·7	55·2
Isolate from castor	Cotton	23	6	47·9	26·0
	Castor	29	11	60·4	37·9
	Sunn-hemp	35	13	72·9	37·1
	Guar	32	12	66·6	37·5
	Til	46	20	95·8	43·4
Isolate from sunn-hemp	Cotton	24	8	50·0	33·3
	Castor	17	5	35·4	29·4
	Sunn-hemp	40	15	83·3	37·5
	Guar	30	15	62·5	50·0
	Til	40	15	83·3	37·5
Isolate from *guar*	Cotton	20	5	41·6	25·0
	Castor	26	6	54·1	23·0
	Sunn-hemp	30	10	62·5	33·3
	Guar	26	6	54·1	23·0
	Til	39	25	81·2	64·1
Isolate from *til*	Cotton	19	4	39·5	21·0
	Castor	29	9	60·6	31·0
	Sunn-hemp	20	6	41·6	30·0
	Guar	36	11	75·0	30·5
	Til	43	16	89·5	37·2

Isolations were made from each one of the series and the cultures so obtained were compared with the cultures with which they were infected. In all cases they were found to be the same. The results obtained in the above experiment show that *Fusarium* isolated from the above-mentioned crops is also capable of causing root-rot in case of all the crops. This shows that *Fusaria* isolated from different crops are pathologically similar.

MORPHOLOGY OF THE ROOT-ROTTING FUNGI

Various types of *Rhizoctonia* isolated from different crops were grown along with a known culture of *Rhizoctonia bataticola* (Taub.) Butl. obtained from the Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi, on potato dextrose agar and oatmeal agar. Measurements of sclerotia and breadth of mycelium were taken. In all the cases, measurements of the

breadth of mycelium and sclerotia were found to be the same. Diameters of sclerotia were found to range between 60-120μ.

These isolates never formed pycnidia although they were grown in several other media and media with varying *p*H. Morphologically these isolates resembled *Rhizoctonia bataticola* (Taub.) Butl. in all respects and therefore they have been given that name.

The *Fusaria* isolated from the affected roots of the above-mentioned crops were grown on Wollenweber's [1925] standard média for *Fusarium*.

Colours of the mycelium were noted after 14 days growth. Measurements of 200 spores in each case were taken on 2 per cent potato dextrose agar. Aerial mycelium was present in all cases. Bluish green sporodochia were also present while sclerotia were absent. Only in case of isolate from *til*, there was a concentration of spores on the surface of the medium, resembling a pionnote. Terminal chlamydospores were produced in abundance by each isolate on practically every medium while the inter-calary chlamydospores were mostly produced on potato cylinder or steamed rice. The length and breadth of micro- and macro-conidia were found to be the same in all cases and were found to vary in the following range :

0—Septate	(6—15)	(3—6)μ
1—Septate	(9—20)	(3—6)μ
2—Septate	(13—33)	(3—7)μ
3—Septate	(25—40)	(3—7)μ

Discussion

The isolations carried out in this study have shown that root-rot in cotton and certain other crops is caused by a species of *Rhizoctonia* and *Fusarium*. It has already been reported by Prasad [1944] that *Fusarium coeruleum* (Lib.) Sacc. is associated with root-rot of cotton in Sind. On careful comparison of the cultures of all the *Fusaria* isolated from the above-mentioned crops, it has been definitely established that they belong to the species of *Fusarium coeruleum* (Lib.) Sacc. A similar study of *Rhizoctonia* sp. isolated from the affected roots has indicated that it belongs to *Rhizoctonia bataticola* (Taub.) Butl.

Summary

Isolations carried out from the rot-affected roots of cotton, castor, sunn-hemp, *guar* and *til* yielded cultures of *Rhizoctonia* and *Fusarium*. Both of these fungi were found to be parasitic and further isolates of each one of them from different crops were found to be morphologically and pathologically similar. They were identified as *Rhizoctonia bataticola* (Taub.) Butl. and *Fusarium coeruleum* (Lib.) Sacc.

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RHIZOCTONIA ROOT-ROT OF *PAN* (*PIPER BETLE*) IN RELATION TO MANURING

By S. Chowdhury, Plant Pathological Laboratory, Sylhet, Assam

(Received for publication on 17 June 1944)

Root-rot of *pan* (*Piper betle* Linn.) due to *Rhizoctonia solani* Kuhn is very serious in Assam and causes heavy damage to the crop wherever it occurs. Mustard oilcake is the only manure used for *pan*. It is ground very fine, spread along the ridges and then covered with a very thin dressing of soil. During the first year of planting oilcake is applied at the rate of 12 md. per acre and during the subsequent years it is applied at the rate of 36 md. per acre. Manuring is done during the rains, once a month commencing from May and ending in September or October. Equal quantities of manures are applied at each application. In all, usually five or six applications are made during a year.

Oilcake is an organic manure and it was presumed that it might serve as a nutrient medium for the growth of *Rhizoctonia* and might influence the root-rot disease of *pan* and that the virulence of the disease might be checked or minimized

by replacing oilcakes by fertilizers. Had this been possible it might have been possible to control the disease to a certain extent by this indirect method.

In order to test the truth of this assumption and the possibility of checking completely or partly the disease by manuring the plants with fertilizers an experiment was carried out. The results of this experiment are recorded in this paper.

Materials and methods

The experiment was laid out in a *boroj* land where all the plants have died of *Rhizoctonia* root-rot. The land was given an additional dose of infective material by incorporating with the soil cultures of *Rhizoctonia solani* Kuhn grown on sterilized paddy straw. The entire plot was divided into six blocks and each block into five plots of equal size. The randomized block system of layout was followed. Each plot was 45 ft.×12 ft. There were 30 rows in each plot and 10 *pan* setts were planted on each row. Planting was done on 15 September 1940 and only healthy setts were planted.

The first manuring was done during the first week of May, 1941 and the subsequent manurings during the months June, July, August, September and October, 1941.

During the second year manuring was commenced in April and ended in September, 1942. Six applications were made, one application in each of the months April, May, June, July, August and September.

In every case the manuring was done the same day and at the same time. The method of application was also the same. The oilcake was ground very fine, then spread along the ridges and afterwards covered with a thin layer of fine earth. The fertilizers, on the other hand, were mixed with an equal quantity of fine earth, thoroughly mixed together and then applied along the ridges just like oilcake and then covered with a thin layer of soil.

The treatments were as follows :

A. *Mustard oilcake.* Applied at the rate of 984 lb. per acre during the first year, 1941, and at the rate of 2952 lb. during the second year, 1942. Samples of the oilcake applied were analysed and found to contain on an average 5·1 per cent nitrogen, 3·13 per cent phosphoric acid and 1·35 per cent of potash.

B. *Sodium nitrate.* Applied at the rate of 321 lb. per acre during the first year, 1941, and at the rate of 963 lb. during the second year, 1942. The samples were found to contain on an average 15·6 per cent of nitrogen.

C. *Ammonium sulphate.* Applied at the rate of 242 lb. per acre during the first year, 1941, and at the rate of 726 lb. per acre during the second year, 1942. The samples were found to contain on an average 21·0 per cent nitrogen.

D. *Mixture of sodium nitrate, superphosphate and potassium sulphate.* A mixture containing 321 lb. of sodium nitrate, 200 lb. of superphosphate and 25 lb. of potassium sulphate was applied per acre during the first year, 1941, and a mixture containing 963 lb. of sodium nitrate, 600 lb. of superphosphate and 75 lb. of potassium sulphate during the second year, 1942. Superphosphate was found to contain 16 per cent of phosphoric acid and potassium sulphate 48 per cent of potash.

E. *Mixture of ammonium sulphate, superphosphate and potassium sulphate.* A mixture containing 242 lb. of ammonium sulphate, 200 lb. of superphosphate and 25 lb. of potassium sulphate was applied per acre during the first year, 1941 and a mixture containing 726 lb. of ammonium sulphate, 600 lb. of superphosphate and 75 lb. of potassium sulphate during the second year, 1942. The percentages of phosphoric acid and potash were the same in superphosphate and potassium sulphate respectively as in D.

Experimental results

After manuring the number of deaths occurring in each of the plots was noted and are recorded in Tables I and II for the years 1941 and 1942. The dead plants were collected and examined ; it was found that in all cases the deaths occurred due to the attack of the parasite *Rhizoctonia solani* Kuhn.

It will be observed from the data presented in Tables I and II that the percentage of death is practically the same for all the treatments, there being no significant difference. As regards the yield of leaves it will be noted that it is slightly more in the oilcake-treated plots during both the years than in the plots treated with the fertilizers.

As to the general growth of the plants due to manuring it was found that the effects of the artificials were earlier visible on the plants than oilcake but in the long run no difference could

be noticed between the plants given different treatments ; the height of the plants, the size and colour of the leaves and the general vigour of the plants were indistinguishable. But during the cold weather and early part of the dry season (November-April) it was found that the oilcake-treated plants were in a better state of health and thriftiness than those receiving the artificials. This is probably due to the fact that oilcake increases the organic matter and humus content of the soil and thus helps the conservation of moisture. Further, the plant food materials contained in oilcake become gradually and slowly available to the plants ; thus its effects are more lasting than the effects of the artificials. Another distinct advantage of oilcake over artificials was also noticed ; it was found that in a region of heavy rainfall like Assam the chances of the manure getting washed away by the heavy showers is more with respect to the artificials than with oilcake.

The same experiments were repeated during the years 1942 and 1943 and results exactly similar to those cited above were obtained.

TABLE I

Effect of manuring on the incidence of Rhizoctonia *root-rot of* pan *(1941)*

Treatments	Pounds of fertilizing ingredients applied per acre			Replication	Total number of setts planted	Number of deaths during the year	Percentage of death	Average percentage of death for the treatment	Yield of leaves	Average yield of leaves for the treatment
	N_2	P_2O_5	K_2O							
				1	300	52	17·3		11,904	
				2	300	62	20·6		11,424	
A	50·18	30·8	13·28	3	300	56	18·6	19·4	11,712	11,600
				4	300	72	24·0		10,944	
				5	300	49	16·3		12,048	
				6	300	59	19·6		11,568	
				1	300	61	20·3		9,799	
				2	300	52	17·3		10,168	
B	50·76			3	300	70	23·3	19·36	9,200	9,852·8
				4	300	52	17·3		10,024	
				5	300	54	18·0		10,086	
				6	300	60	20·3		9,840	
				1	300	58	19·3		9,922	
				2	300	62	20·6		9,758	
C	50·82			3	300	50	16·6	19·68	10,250	9,873·6
				4	300	69	23·0		9,471	
				5	300	56	18·6		10,004	
				6	300	60	20·0		9,837	
				1	300	51	17·0		10,207	
				2	300	59	19·6		9,881	
D	50·76	32·0	12·0	3	300	48	16·0	19·53	10,323	9,895·1
				4	300	69	23·0		9,476	
				5	300	57	19·0		9,963	
				6	300	68	22·6		9,521	
				1	300	61	20·3		9,780	
				2	300	52	17·3		10,187	
E	50·82	32·0	12·0	3	300	47	15·6	19·51	10,376	9,845·8
				4	300	69	23·0		9,482	
				5	300	53	17·6		10,032	
				6	300	70	23·3		9,210	

TABLE II

Effect of manuring on the incidence of Rhizoctonia *root-rot of* pan *(1942)*

Treatments	Pounds of fertilizing ingredients applied per acre			Replication	Total number of setts planted	Number of deaths during the year	Percentage of death	Average percentage of death for the treatment	Yield of leaves	Average yield of leaves for the treatment
	N_2	P_2O_5	K_2O							
				1	248	39	15·7		15,049	
				2	238	31	13·02		14,894	
A	150·55	92·4	39·85	3	244	39	15·9	15·08	14,742	14,749·5
				4	228	29	12·7		14,297	
				5	251	42	16·7		15,046	
				6	241	40	16·5		14,469	
				1	239	28	11·7		14,769	
				2	248	41	16·5		14,496	
B	152·28			3	230	37	16·07	15·26	13,497	14,335·2
				4	248	39	15·7		14,629	
				5	246	42	17·07		14,276	
				6	240	35	14·5		14,329	
				1	242	41	16·9		14,069	
				2	238	30	12·6		14,559	
C	152·46			3	250	38	15·2	15·31	14,829	14,366·0
				4	231	36	15·5		14,252	
				5	244	39	15·9		14,349	
				6	240	38	15·8		14,138	
				1	249	47	18·8		14,139	
				2	241	36	14·9		14,349	
D	152·28	96·0	36·0	3	252	43	17·06	15·85	14,629	14,314·3
				4	231	29	12·5		14,132	
				5	243	41	16·8		14,245	
				6	232	35	15·08		13,792	
				1	239	41	17·1		13,858	
				2	248	39	15·7		14,598	
E	152·46	96·0	36·0	3	253	46	18·1	15·80	13,927	14,364·8
				4	231	32	13·8		14,399	
				5	247	40	16·2		14,476	
				6	230	31	13·9		14,931	

CONCLUSIONS AND SUMMARY

As a result of the experiments conducted with different manures it was found that the percentage of death of *pan* plants due to the attack of *Rhizoctonia solani* Kuhn is not influenced by the nature of the fertilizing material. The percentage of death has been found practically the same in the plots receiving oilcake, sodium nitrate, ammonium sulphate singly or sodium nitrate or ammonium sulphate in combinations with superphosphate and potassium sulphate. The yield of leaves, however, has been found slightly more in the oilcake treated plots.

ACKNOWLEDGEMENTS

My thanks are due to Dr G. W. Padwick, Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi, for critically going through the manuscript.

A LEAF SPOT OF *CARICA PAPAYA* L. CAUSED BY A NEW SPECIES OF *PHYLLOSTICTA*

By S. Chowdhury, Plant Pathological Laboratory, Sylhet, Assam

(Received for publication on 29 June 1941)

(With Plate XII and one text-figure)

At Haflong (Assam) and its vicinity in the North Cachar Hills *papaya* (*Carica papaya* L.) is grown extensively by the hill people. The plants are raised on the hill slopes and once established they receive practically no care.

In 1940, a very serious leaf spot due to a species of *Phyllosticta* was first noticed in these plantations. The disease has been observed ever since and causes considerable annual damage. It is as a rule prevalent in the months of September to January after which it is practically absent. The disease has not so far been observed in any other part of Assam.

Symptoms of the disease

The spots are restricted entirely to the leaves, and vary considerably in size; some are small and roundish, being a millimeter in length and a millimeter or three-fourths of a millimeter in breadth; others are irregular, oval or elongated having a size 3-15 mm. in length and 2-11 mm. in breadth. The spots are almost white in the centre and often bounded by a yellowish or brownish margin which gradually merges into the normal green of the leaf. The central portion of the spots is thin and papery and ultimately becomes brittle and falls out, giving a shot-hole appearance. In this portion are seen a number of minute dark brown to black pycnidia. The spots are usually isolated but may become confluent, forming big patches. Sometimes a large number of spots develop on the leaf, which then turns brown, dries up and is shed. Plate XII shows the symptoms of the disease.

Morphology of the parasite on the host

Pycnidia. The pycnidia (Fig. 1, *a*) are formed on the dead portions of the leaf spots, on the upper surface. They are at first sub-epidermal but later become erumpent. They are globose to sub-globose, usually with distinct ostioles, dark brown to black and measure 80-115 × 60-95 μ.

In sections the pycnidial wall is thin below, consisting of one or two layers of dark coloured stroma, but is much thicker at the top; after the formation of the ostiole the thickened wall persists around the short neck. Next to the wall within are the narrow sporogenous layers of hyaline parenchyma cells bearing the conidiophores.

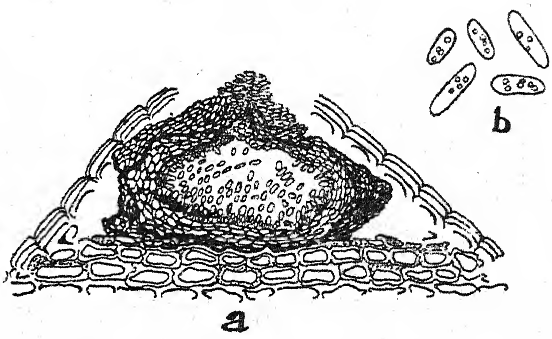

Fig. 1.—*a* : Section through a pycnidium; *b* : Pycnospores

Pycnospores. The pycnospores are liberated through the ostiole in a mucilaginous mass. They are hyaline to sub-hyaline, straight to rarely slightly curved, rounded at both ends. They range from 5-10 μ in length and 2·5-3 μ in width.

Conidiophores. The conidiophores arise from a hyaline sporogenous layer of cells which is supported by a colourless pseudoparenchymatous sheath lining the dark wall of the pycnidium. The sporogenous layer is composed of very small and narrow cells from which the conidiophores arise. The conidiophores are simple and unicellular.

Mycelium. The mycelium permeates the entire area of the leaf spot and even extends slightly to the surrounding area. The hyphae are both inter- and intra-cellular and septate and branch irregularly.

Isolation and inoculation experiments

Isolation. The fungus was readily brought

into culture by transferring surface sterilized bits of affected portions of leaves to oat agar plates. A large number of isolations were made, all of which yielded the same fungus.

Inoculation experiments. Inoculation experiments were carried out on *papaya* plants both in the laboratory and in the fields. For conducting the inoculation experiments in the laboratory plants were raised in pots and then subjected to infection. Two methods were followed: spore suspension in sterile water was sprayed on the leaves, or a culture containing the mycelium and crushed pycnidia was placed on unwounded surfaces of the leaves. All the plants after inoculation were kept closed in a glass house, which was kept moist by occasional spraying with sterile water. After 24 to 48 hours the plants were removed from the glass house and kept in the open. They were occasionally sprayed with sterile water.

Fifty-two plants were treated in this way. All the plants took infection. When cultures containing mycelium and crushed pycnidia were used as inocula the signs of infection were visible in 4 to 6 days; in case of spore suspensions the symptoms were apparent after 12 to 17 days. The inocula were placed both on the upper and the lower surfaces of the leaves but infections were successful only when the inocula were placed on the upper surface. All the controls remained healthy.

In the field, infection experiments were carried out by means of bits of culture containing mycelium and crushed pycnidia of the fungus. Leaves of the plants were first sprayed with sterile water and then the inocula were placed at selected places on the upper surfaces of the leaves by a sterile needle. The inocula were thereafter covered with small pieces of sterile absorbent cotton made wet by dipping in sterile water. The inoculated leaves were sprayed with sterile water from time to time in order to keep the inoculated places moist. After four to six days, infection became visible. In all 217 inoculations were made on a number of plants in the different plantations at Haflong and Jatinga in the North Cachar Hills and 97 per cent of the inoculations were successful. Plants that were left uninoculated but otherwise given the same treatments and were standing in close proximity to those inoculated remained healthy.

All these experiments prove beyond doubt that the fungus is an active parasite.

From all the infected plants the original fungus was reisolated in every case.

Growth in culture

The fungus was grown on oat agar and on *papaya* leaf juice agar. Mycelial growth was good on both the media. Aerial growth was scanty, much of it was submerged and of a spreading nature. Pycnidial formation was more abundant on *papaya* leaf juice agar than on oat agar.

The mycelium in both the media consisted of septate, pale green hyphae which branch irregularly. The mode of branching, the irregular form, size and the bulging of the cell walls are very characteristic. The young hyphae are long, slender; septa are rare and the walls are not constricted. Anastomosis is frequent along the walls.

In the old hyphae the cells are short and thick and occupied by large globules of a greenish colour; septation is frequent and the walls are prominently constricted at the septa and at the bases of the short, stout branches that arise at irregular angles.

In culture the pycnidial formation starts on the 5th or 6th day. The pycnidia are light brown at first but with age the colour deepens and finally they turn dark brown to almost black. They are slightly bigger than those formed in nature measuring 90-127 $\times$ 67-107 μ. Each pycnidium has an ostiole and a short neck. Some are spherical but in the majority of cases they are sub-globose.

The pycnospores are formed in abundance within the pycnidia. They are liberated from the pycnidia through the ostiole in a mucilaginous mass. They are hyaline to sub-hyaline, straight to rarely slightly curved and rounded at both ends. They measure from 5 to 10 μ in length and 2·5 to 3 μ in width.

Identification of the parasite

On going through the relevant literature it was found that two species of *Phyllosticta* have been recorded on *Carica papaya*. They are *Phyllosticta Papayae* Sacc. and *P. Caricae-Papayae* Allesch. The reported spore measurement data of these two fungi along with that of *Phyllosticta* sp. from North Cachar Hills are recorded in Table I.

Symptoms of the disease

TABLE I

Comparative spore measurements of species of Phyllosticta *occurring on* Carica papaya

Fungus	Dimensions of spores	Colour of spores
Phyllosticta Papayae .	2·5—3·5×1 μ	Hyaline
P. Caricae-Papayae .	3·0—4·0×1 μ	Hyaline
Phyllosticta from North Cachar Hills	5·0-10·0×2·5-3μ	Hyaline to sub-hyaline

It is evident from the comparative spore measurement data presented above that the spore measurements of *Phyllosticta* from North Cachar Hills take it outside any probable variation of *Phyllosticta Papayae* and *P. Caricae-Papayae*.

A few diseased *papaya* leaves were sent to Mr E. W. Mason, Imperial Mycological Institute, Kew, Surrey, England, for help in the identification of the parasite. He wrote 'I cannot find that it has been described under any name in our systematic lists'. The fungus is therefore, considered a species new to science for which the name *Phyllosticta sulata* is proposed.

Phyllosticta sulata Chowdhury Sp. Nov.

Pycnidia first sub-epidermal, later becoming erumpent, globose to sub-globose, dark brown to black, 80-115×60-95 μ, usually with distinct ostioles. Pycnospores unicellular, hyaline to sub-hyaline, straight to rarely slightly curved, rounded at both ends, measuring 5-10×2·5-3 μ.

Parasitic on the leaves of *Carica papaya* L. Haflong, Assam, 7 November 1940. Collected by S. Chowdhury.

Type specimen deposited in the Herb. Crypt. Ind. Orient., Imperial Agricultural Research Institute, New Delhi.

Pycnidiis primo sub-epidermalis, tunc erumpentis, globosis vel sub-globosis, atro-brunneis vel nigris, 80-115×60-95 μ, plerumque distincte osteolatis. Pycnosporidiis unicellularis, hyalinis vel sub-hyalinis, rectis vel sub-curvatis, basis et apicis rotundatis, 5-10×2·5-3 μ.

Parasiticis in foliis *Caricae papayae* L., Haflong, Assam, 7 November 1940. S. Chowdhury leg.

Typus in Herb. Crypt. Ind. Orient., Imperial Agricultural Research Institute, New Delhi.

PERPETUATION AND DISSEMINATION OF THE PARASITE

Intensive studies to determine the mode of perpetuation and dissemination of the parasite have not been undertaken. Limited studies and circumstantial evidence, however, have demonstrated that the parasite lives over on infected plant debris in the soil.

In January 1941 pieces of naturally infected leaves were wrapped in tissue paper and carried through the rest of the winter and the summer months under the following conditions:

(i) Hung on the tree in the open.

(ii) Placed on the surface of the ground.

Isolations were made from these materials in August and September 1942 and the fungus was recovered in every instance. Inoculation experiments were carried out by using these isolations as inocula and in 92 per cent cases the infections were successful.

In the *papaya* plantations in the North Cachar Hills, where plants are grown on hill slopes, sanitary methods of cultivation are not at all followed. Fallen leaves of *papaya* plants are allowed to remain and rot in the ground. In every plantation one comes across piles of fallen leaves lying about. From these piles a large number of isolations were made during the years 1941 and 1942, beginning from February and ending in September. In all cases the fungus was recovered. It can thus safely be concluded that the parasite perpetuates in the plant debris in the plantations.

Careful observations indicate that the parasite is disseminated through the agency of wind. The disease has been found to appear every year during the later part of September. During this time there is scanty rainfall but there is an excessive fall of dew, which helps the pycnidia to burst, liberating the pycnospores and allowing them to germinate.

CONTROL AND PREVENTION

From these studies it will be evident that the disease can be controlled by systematic collection and destruction by burning of the affected leaves that lie on the ground and serve as a source of inoculum.

Preventive methods have been carried out with success. In five plantations 20 to 25 plants in each of the plantations were carefully sprayed with one per cent Bordeaux mixture during the latter part of August, 1941; they were given a second spraying on 15 September, a third spraying on 15 October and a fourth on 15 November. Spraying was done carefully so that the surfaces of sprayed leaves were uniformly and thoroughly

covered with the spray fluid. It was found that the sprayed plants were either absolutely free from infection or there were fewer spots on them in comparison with unsprayed control plants in close proximity. The spray trials conducted in 1942 have further brought out the fact that three sprayings (latter part of August, 15 September and 15 October), if carefully and thoroughly done, are sufficient for keeping the disease in check. But if perchance there is a heavy shower immediately after giving a spray it becomes necessary to give the plants an additional spray immediately after the rain.

Above all it has been found that unless efforts are made to destroy the source of infection by the systematic collection and destruction of the affected leaves and burning them, it is not easy to keep the disease under control and to check or minimize the loss it causes.

Summary

A leaf spot of *Carica papaya* L., due to a species of *Phyllosticta*, has been found to occur at Haflong in the North Cachar Hills.

Symptoms of the disease are described. The fungus has been isolated and inoculation experiments carried out. It has been found that the fungus is a virulent parasite.

The fungus has been studied both in culture and on the host and found to be a species new to science, which is given the name *Phyllosticta sulata*.

The parasite survives in the affected leaves lying in the plantations and is disseminated by wind.

It can be controlled by systematic collection and destruction of the affected leaves and prevented by spraying the plants with one per cent Bordeaux mixture.

Acknowledgements

My thanks are due to Dr B. B. Mundkur, Imperial Agricultural Research Institute, New Delhi, for critically going through the manuscript and for valuable suggestions, to Mr E. W. Mason of the Imperial Mycological Institute, Kew, Surrey, England, for help rendered in the identification of the fungus and to Father F. S. Pew, S. J. of the St. Xaviers College, Calcutta, for the Latin diagnosis.

COMPARATIVE STUDIES OF SOME INDIAN PLOUGHS WITH DYNAMOMETER

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(With thirty-six text-figures)

Introduction

As the main operation of stirring or loosening of the soil in agricultural fields for sowing purposes can best be done with plough only, the plough has become an indispensable implement for the agriculturist. Recorded history does not give the origin or the exact date of its coming into existence. However, it appears to have existed in the eastern countries as early as 2500 B. C. In Ramayana its name is mentioned as *Nagali* and in Mahabharata as *Hala*, which terms are still in use in many parts of India. When the idea of agriculture and cultivation entered the mind of man, he tried to prepare seed beds with the help of crowbars and by beating the bulky clods into powder with hammers and axes. This practice of beating the clods appears to have existed in England even in the Saxon period. As man progressed, his needs for agricultural produce multiplied, he began to make attempts to improve upon the primitive devices of seed-bed preparation and succeeded in evolving a plough based on lever principle. From literature it appears that the earliest plough was an irregularly bent branch of a tree. Later on, with the advance of science and civilization, people realized that the economic prosperity of a country depends to a considerable extent on the increased output of the agricultural products. With such an end in view every country took up the problem of improving the plough by applying scientific principles to suit its local conditions and the power available for work. In Europe and America extensive efforts have been made to improve the plough from the draught as well as the efficiency point of view. With the harnessing of mechanical power to agriculture

various attempts have been made to improve the plough by modifying shares, by inserting mouldboards and finally manufacturing them with iron. The discovery of high grade steel has made possible further improvement in the shape of shares. Based on similar principles a number of implements have been designed, including single and multifurrow ploughs. But in India, Egypt and other Asiatic countries little progress in the improvement of plough has been made. Some improvement can, nevertheless, be said to have been made because they are now made in three parts and assembled together instead of a single piece of the primitive type. The strength has been increased to work in all types of soils and at greater depths. A share, i.e. an iron rod, is also used to protect the penetrating end of the wedge from wear and tear and also to ensure deeper cutting. But no experimental records exist to show the processes of evolution to the present models. We find that different provinces in India, and even different places in the same province, have different types of ploughs, some differing in weight, some in size of the wedge, some in length and some in shape.

It will thus be seen that the plough, the universal cultivating implement, was first roughly made out of a branch of a tree, then by the crude carpenter of the early times, and now it is manufactured by trained engineers with all the modern appliances and scientific resources of civilization.

Literature

In foreign countries a systematic study on the shape of ploughs has been made with the help of mechanics and mathematics. Draught measurements were recorded by dynamometer as early as 1840 by Pusely [White, 1918]. The annual report of the New York State Agricultural Society for 1867 [White, 1918] contains a treatise on the geometrical construction of the surfaces of many historical plough bottoms, but no attempts have been made to classify these surfaces on the basis of their mathematical forms. White [1918] has evolved mathematical equations regarding the shape of mould boards and has also given methods for generating suitable mould board surfaces for different soils. In 1920-23, Davies [1924] investigated the relation between (*i*) draught and depth (*ii*) draught and width of the furrows, and showed that a linear relation exists between them. Keen and Haims [1925] carried out some work at Rothamsted and established a hyperbolic relationship between moisture percentag eanddraught. Nichols [1930 ; 1931] studied the various soil constants which would indicate the physical factors affecting tillage and was led to the conclusion that a definite relation exists between friction value, shear resistance to compression and the Atterberg consistency constants. He also mentioned that the general reaction of the soil to an implement was a function of the physical properties indicated by the Atterberg constants and could be predicted for any moisture content. In further dynamic studies of the soil, he established a relationship between friction and hardness of metal of the plough wedge or share and the colloidal contents of the soil. According to him when the colloidal content exceeds 32 per cent, the friction increases slightly and is considered to be the limit for that factor. He found that the polish also affects the frictional value in heavy soils but as no measure of the polish was available no mathematical formula for its effect was obtained.

In Egypt, ploughing is done by wooden ploughs resembling much the Indian ploughs, except that the share is spoon-shaped, as it has to work in soft soils. When the members of the Royal Commission on Agriculture in India [Middleton, Calvert and Gangulee, 1928] were touring Egypt they were informed that attention had been given to the possibility of improving the local plough but could not be done at the price at which the competing implements would have to be sold in Egypt.

In India, Charley did some work in Madras mostly on foreign ploughs, but the data and methods followed in conducting these experiments are not available. Godbole [1913] designed a new plough and compared it with the existing Deccan plough by finding the average resistance required to open unit area of the cross-section of the furrow with the help of a spring balance dynamometer having a pointer moving on a calibrated circular dial. He has mentioned that the centre of gravity of the plough should be very near the point where the beam is fixed to the body. Clouston [1906], after making comparative studies of foreign and Indian agricultural implements, expressed the view that the manufacturers of foreign ploughs have not considered the Indian agriculturists' point of view. He modified the foreign ploughs to suit Indian conditions by introducing a wooden beam in place of chain and iron beam and finally was of the opinion that the Swedish plough with the above modifications gave satisfactory performance.

However, he did not give any data to substantiate his conclusions. Henderson [1909] designed a

wooden plough based mainly on experience. This plough works satisfactorily on irrigated tracts of Sind. On the basis of theoretical arguments Miller Brownlie [1922] was of the opinion that a plough having the line of draw-bar-pull coinciding with that of the resultant of the forces due to the soil on the plough, will work efficiently even if the ploughman is not very attentive. Mayadas and Hansraj [1931] carried out some tests to judge the efficiency of some improved ploughs by finding the average resistance per unit area of the cross-section of furrow and horse power required to work them. In these experiments they used spring-balance-dynamometer similar to the one used by Godbole. They also worked them over equal areas and compared the nature of tilth and the time taken by them. Mason Vaugh, Agricultural Engineer at Naini Institute, Allahabad, did some work on ploughs but he has concentrated his attention on iron ploughs only. He has designed a plough with four adjustments which can be used for four different operations with slight adjustment of the parts. Cliff [1927], while designing a cultivator, studied the relative merits of all the implements that would be useful on an agricultural farm. He found that the Indian ploughs leave (Δ-shaped) ridges between furrows untouched and if the stirring was to be done at a uniform depth throughout the field, a number of cross-ploughings were required and this would take more time. In his view all foreign designs were unsuitable to Indian condition and a suitable design would find a good market in India irrespective of its cost. However, he did not attempt to design a new plough as his efforts were concentrated on his cultivator. Some dynamometer tests on agricultural implements were conducted at Pusa (Bihar), but most of these tests were restricted to the utility of tractors and foreign implements for Pusa conditions.

Objects and methods

From the brief review of literature given above it will be seen that much work has not been done in India on *desi* ploughs used in different parts of India. With the object of making a comparative study, a number of *desi* ploughs were collected at Delhi from different parts of India and attempts are made in this paper to classify them from (*i*) constructional, (*ii*) soil, (*iii*) climatic, (*iv*) crop, (*v*) depth and width of furrow, and (*vi*) draw-bar-pull points of view.

Before classifying the ploughs, we will first give brief description of all the ploughs used in these experiments. The notations adopted are indicated in Fig. 35.

Brief description of ploughs with other details

(1) *Bellary plough* (*Madras*). The dimensional diagram is given in Fig. 1. The wedge and the body are made in one piece and the beam is fixed to the body at a distance of 5 in. from the inner bend between body and wedge. The body, wedge and beam are made of acacia, i.e. *babul* wood. The beam is of rectangaular cross-section 3 in. × 4 in., its length being 9 ft. 2 in. The thickness and width of the body in the direction and perpendicular to beam are 5 in. and 7 in. respectively at the place where the beam is fixed to it. The wedge is a pyramid of equilateral triangular cross-section having the maximum section 6 in. side and the vertex of the section facing downwards. The length of the wedge up to the body is 32 in. and up to its intersection with the beam is 40 in. The angle of the wedge, i.e. the face angle of wedge at the penetrating point is 16° and the angles which the wedge makes with the body and beam are 135° and 42·5° respectively. A handle is fixed to the beam at the back of the body. The length of the share, i.e. an iron rod used to protect the penetrating point of the wedge from wear and tear, is 26·5 in. The weight of the plough is 81·5 lb. This plough is used in black soils of Bellary and Kurnool districts. The crops generally grown in these districts are *jonna* (*Andropogon sorghum*), *Tenai* (Italian millets) and cotton. The ploughing is usually done to a depth approximately 8 in. The plough is used mainly in rainfed area. The average monthly rainfall, on the basis of 37 years, for these districts is as follows: January = 0·59 in., February = 0·32 in., March = 0·48 in., April = 1·44 in., May = 2·36 in., June = 1·46 in., July = 1·46 in., August = 1·13 in., September = 1·51 in., October = 6·41 in., November = 3·75 in., and December = 1·18 in. Two pairs of Mysore bullocks, having a live weight 700 to 900 lb., are used to work this plough as it is a heavy plough.

(2) *Coimbatore plough* (*Madras*). The dimensional diagram is given in Fig. 2. The wedge and the body are made in one piece and the beam is fixed to the body very near the inner bend between the wedge and body. The wedge and the body are made of acacia and the beam from salwood. The beam is of rectangular cross-section $1\frac{1}{2}$ in. × 3 in. very near the body, and is of oval section for the remaining portion, the length being 11 ft. 7 in.

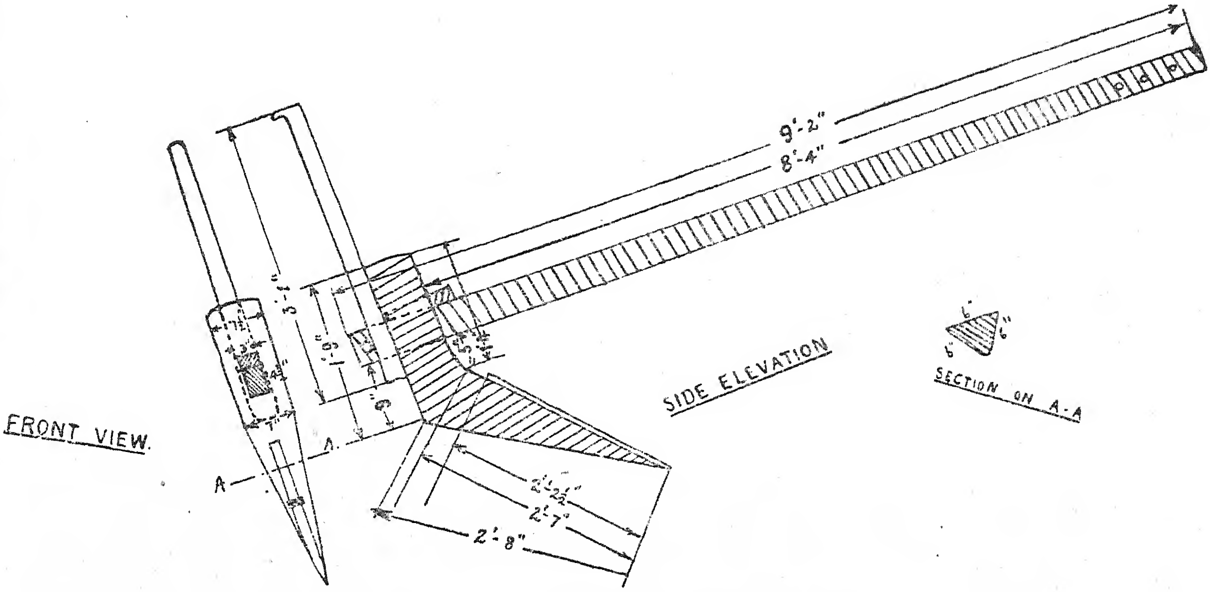


Fig. 1. Heavy country plough, Bellary (Madras)

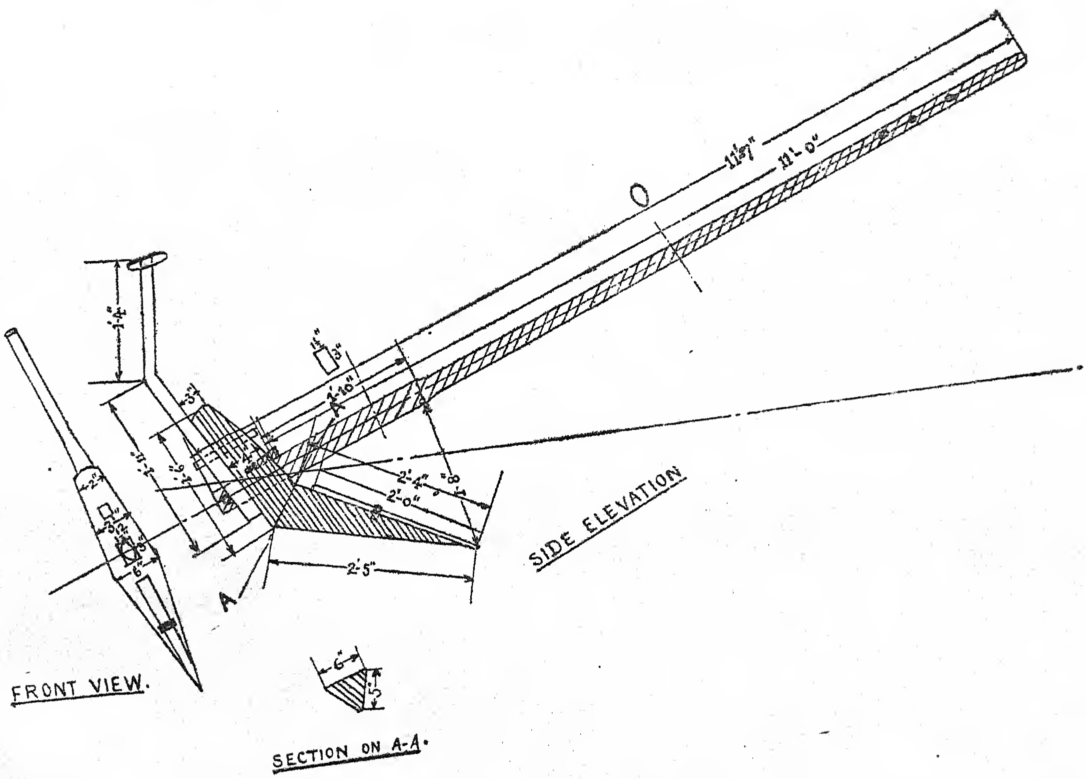


Fig. 2. Country plough, Coimbatore (Madras)

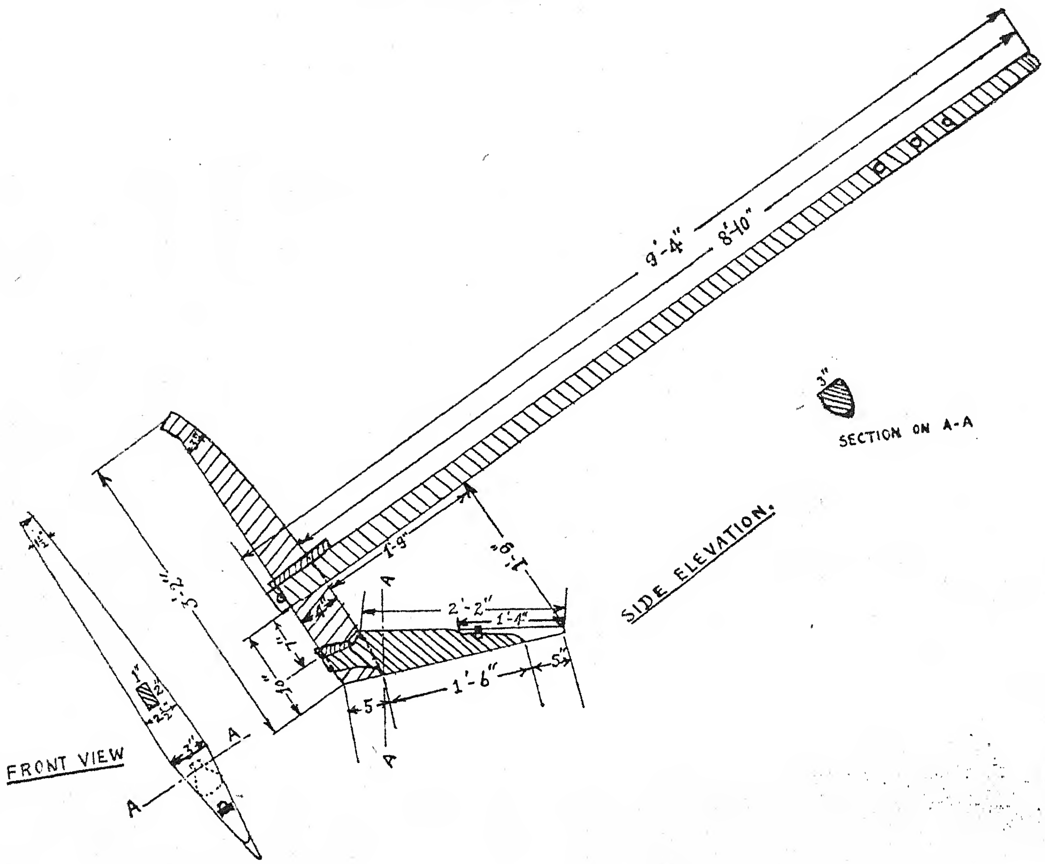
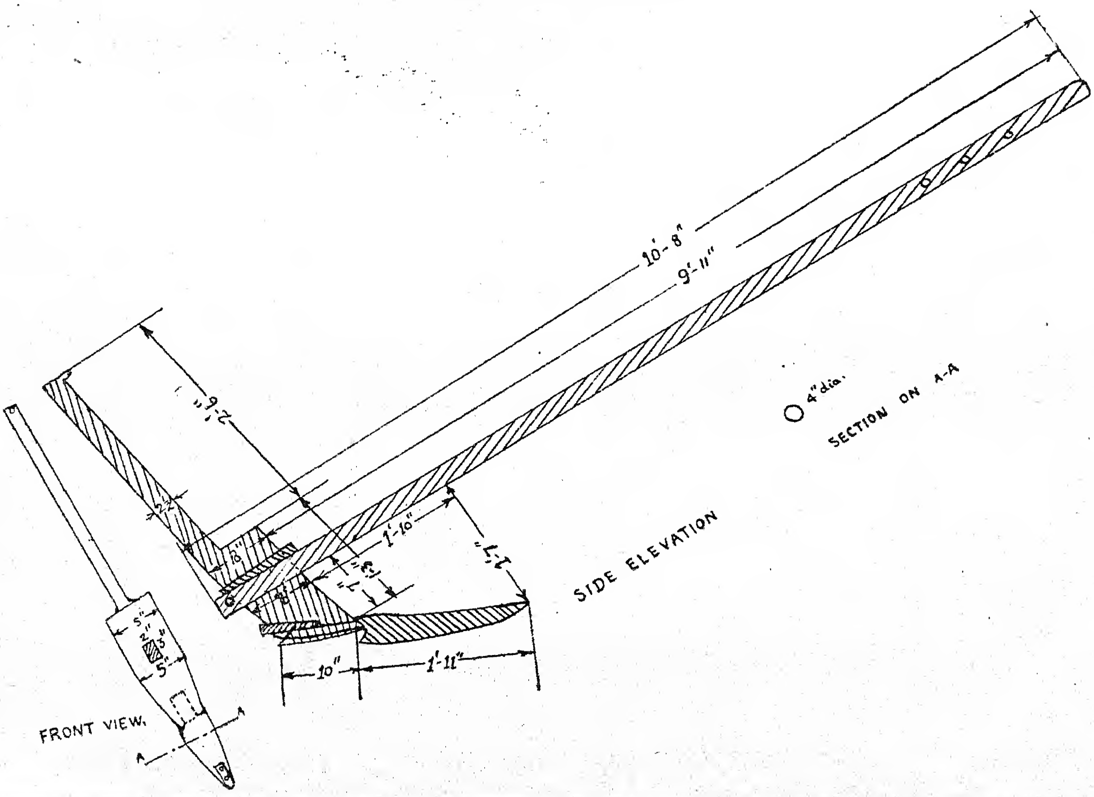


Fig. 3. Country plough, Dohad (Bombay)



The body, at the place where the beam is fixed to it, is trapezium in section 6 in. × $4\frac{1}{2}$ in. × 3 in. × $4\frac{1}{2}$ in. The wedge is pyramid of an isosceles triangular section, having the sides and base at maximum section 5 in. and 6 in. respectively and the vertex facing downwards. The face angle of the wedge is 12·4° and the angles which the wedge makes with the body and beam are 153° and 40·96° respectively. The length of the wedge up to the body is 29 in. and up to its intersection with the beam 34 in. A handle is fixed to the beam at the back of the body. The length of share is 24 in. The weight of the plough is 37·4 lb., having the centre of gravity very near the inner bend. This plough is used in light, heavy, black, red, garden and wet lands of Coimbatore and other neighbouring districts. The crops generally grown are paddy, cotton, pulses and cereals. The ploughing is done when the soil is fit to a depth of 3 in. to 4 in. It is used in both irrigated and rainfed tracts. The average monthly rainfall is as follows: January = 0·59 in., February = 0·32 in., March = 0·48 in., April = 1·44 in., May = 2·36 in., June = 1·46 in., July = 1·46 in., August = 1·13 in., September =1·51 in., October = 6·41 in., November = 3·75 in., and December = 1·18 in. A pair of Kangayam bullocks of live weight 800-900 lb. each is used for light soils and 1000 to 1200 lb. for heavy soils to work this plough.

(3) *Country plough, Dohad (Bombay).* The dimensional diagram is given in Fig. 3. The body and the wedge are made in two pieces, and assembled together such that they appear to have been made in one piece. The beam is fixed to the body at a distance of 7 in. from the inner bend between body and wedge. The plough is made of salwood. The beam is of rectangular cross-section 1 in. × 2 in. and its length being 9 ft. 4 in. The body and the handle are made in one piece and the body at the place where the beam is fixed to it is of rectangular cross-section 4 in. × 3 in., and at the place where the wedge is fixed to it is of rectangular section 5 in. × 3 in. The wedge is very narrow having a cross-section of more than half an ellipse cut by a line parallel to minor axis, the flat face facing upwards. The face angle of the wedge is 8·2° and the angles which the wedge makes with the body and beam are 122° and 43° respectively. The length of the wedge up to the body is 18 in. and up to its intersection with the beam is 35 in. The length of share is 16 in. and protrudes 5 in. outside the wedge. The weight of the plough is 28·7 lb. This plough is used in soils varying from light to black of the eastern parts of Panchmahals. The crops generally grown are maize, groundnuts, paddy, wheat, gram; and ploughing is done to a depth of 4 in. to 6 in. in dry tracts. It is used in both irrigated and rainfed tracts. The average monthly rainfall is as follows: January = 0·11 in., February = 0·16 in., March = 0·08 in., April = 0·04 in., May = 0·51 in., June = 4·34 in., July = 8·87 in., August = 7·60 in., September = 5·58 in., October = 1·10 in., November = 0·19 in., and December = 0·11 in. A pair of Malvi bullocks with a live weight of 700 lb. and with a height of 4 ft. is used to work this plough.

(4) *Country plough, Baroda (Bombay.)* The dimensional diagram is given in Fig. 4. The wedge and body are made in two parts and assembled together as shown in the diagram. The beam is fixed to the body leaving a clearance of 7 in. from the place where the wedge is fixed to the body. The beam is of rectangular cross-section 2 in. × 3 in., its length being 10 ft. 8 in. The body is a rectangular solid with cross-section 8 in. × 5 in. and 10 in. × 4 in. where the beam and wedge are fixed to it respectively. The body and the handle are made in one piece. The wedge is approximately a cone having 4 in. diameter at the maximum section, the angle of cone being 13·3°. The angles which the wedge makes with the body and beam are 140° and 37·6° respectively. The length of the wedge up to the body is 23 in. and up to its intersection with the beam is 36 in. The length of the share is 6 in. The weight of the plough is 50·7 lb. This plough is used in light alluvial soils (known as Gorat) of Baroda and surrounding places. The crops generally grown are *bajara*, *kodra* (*Eleusine coracana*), *bawta* and tobacco. The ploughing is done usually to a depth of 5 to 6 in. when the moisture content of the soil varies from 15 to 30 per cent. It is used mainly in rainfed areas and the average monthly rainfall is as follows: January = 0·40 in., February =0·00 in., March = 0·00 in., April = 0·00 in., May = 0·00 in., June = 4·69 in., July = 14·45 in., August = 3·65 in., September = 10·00 in., October =1·06 in., November = 0·00 in., and December = 0·00 in. A pair of bullocks with 54 in. height behind hump, and girth of 75 in. having a length of 61 in. from shoulder to pin bone, and a live weight varying between 800 to 1200 lb. each is used to work this plough.

(5) *Country plough, Indore (Central India).* The dimensional diagram is given in Fig. 5. The wedge and the body are made in two pieces and assembled together with a fine joint so that they

appear to have been made in one piece. The beam is fixed to the body at a distance of $7\frac{1}{2}$ in. from the inner bend between the wedge and body and is of rectangular cross section $1\frac{1}{2}$ in. $\times$ 3 in., its length being 10 ft. 4 in. The body is a rectangular solid with cross-sections 4 in. $\times$ 3 in. and 5 in. $\times$ 2 in. at the places where the beam and wedge are fixed to it respectively. The body and handle are made in one piece. The wedge is similar to that of Dohad, with flat face facing upwards as shown in Fig. 5. The length of the wedge up to the body is 20 in. and up to its intersection with the beam is 30 in. The face angle of the wedge is 10°, and the angles which the wedge makes with the body and beam are 133° and 42·5° respectively. The length of the share is 6 in. The plough is made of salwood and its weight is 56·9 lb. This plough is used in medium black to heavy black clay soils of Malwa plateau. The crops generally grown are *jowar*, cotton, wheat, gram, linseed, peas, etc. Ploughing is done occasionally as annual ploughing is not practised except for special crops such as sugarcane, etc. When ploughing is done, it is usually done after rains and to a depth of 5 in. to 6 in. This plough, though mainly used in rainfed tracts, is used in irrigated tracts as well. The average monthly rainfall is as follows: January = 0·28 in., February = 0·18 in., March = 0·06 in., April = 0·14 in., May = 0·58 in., June = 5·70 in., July = 9·87 in., August = 8·01 in., September =6·53 in., October = 1·15 in., November = 0·41 in., and December = 0·21 in. A pair of Malvi bullocks with an average length of 5 ft. 2 in., height 4 ft. 10 in. and live weight of about 1,224 lb. each is used to work this plough.

(6) *Sarkar plough, Sind* (*Egyptian type*). The dimensional diagram is given in Fig. 6. This model is completely different from the other Indian ploughs and is known as Egyptian type. This was designed by Henderson. There is no body and the wedge serves both purposes. The beam and the wedge are fixed together by means of a bolt rod at a distance of 16 in. from the pointed edge of the wedge and another bolt at the other end of wedge. This method of tightening enables us to alter the angle between the beam and wedge whenever required. The beam is of rectangular cross-section 2 in. $\times$ 3 in., its length being 9 ft. The cross-section of the wedge perpendicular to its length is four sided, one of the sides being an arc of a circle and facing downwards. The cross-section of the wedge along its length is a triangle up to 16 in. from the pointed end and a rectangle for the remaining portion. The total length of the wedge is 30 in. The angle which the wedge face makes with the beam is 40·96°. A flat iron plate is used as share to protect the wedge. A separate handle is fixed to the beam at a distance 8 in. from the bolt rod. The weight of the plough is 33·3 lb. This plough is used in soils varying from sandy loam to clay loam of Hyderabad, Tharparkar and Nawab Shah districts of lower Sind. The crops generally grown are cotton, wheat and oilseeds and ploughing is done to a depth of 3 to $3\frac{1}{2}$ in. after irrigation. The plough is used in irrigated tract only. The average monthly rainfall is as follows: January = 0·20 in., February = 0·27 in., March = 0·24 in., April = 0·05 in., May = 0·20 in., June = 0·45 in. July = 2·85 in., August = 2·12 in., September = 0·60 in., October = 0·02 in., November = 0·06 in., and December = 0·06 in. A pair of Karachi bullocks with a live weight of 800 to 900 lb. and height of 4 ft. 5 in. each or a pair of Tharparkar bullocks with a live weight 900 to 1000 lb. and height 4 ft. 8 in. each is used to work this plough.

(7) *Kannar plough* (*Sind*). The dimensional diagram is given in Fig. 7. This is an iron plough with a modified mould board and a wooden beam. The share and mould board are attached tightly to the body with the help of bolts and nuts. A wooden beam of rectangular cross-section 2 in. $\times$ 3 in. is fixed to the body by means of bolt and nuts and its length is 9 ft. 5 in. The furrows opened by this plough are not triangular in cross-section as is the case with the other Indian ploughs. The share of this plough opens furrows 4 in. to 6 in. wide at the bottom. Other particulars can be seen from the diagram. The weight of the plough is 37·9 lb. This plough is used in rainfed areas and also in the same tracts as the Sarkar plough, with the same animals. The ploughing is done to a depth of $3\frac{1}{2}$ in. to 4 in.

(8) *Native plough* (*Sind*). The dimensional diagram is given in Fig. 8. The wedge, body and the handle are made in one piece. All the three form an arc when viewed from the side of the plough. The beam is fixed to the body by means of cotters and the cross-section of the body where the beam is fixed to it is 4 in. $\times$ 4 in. The beam is of rectangular cross-section $1\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. and its length is 9 ft. 9 in. The wedge is a pyramid of a pentagonal cross-section with four equal sides. The equal sides at the maximum section are 3 in. each, the fifth side which faces upwards measures 5 in. The length of the wedge up to the body is

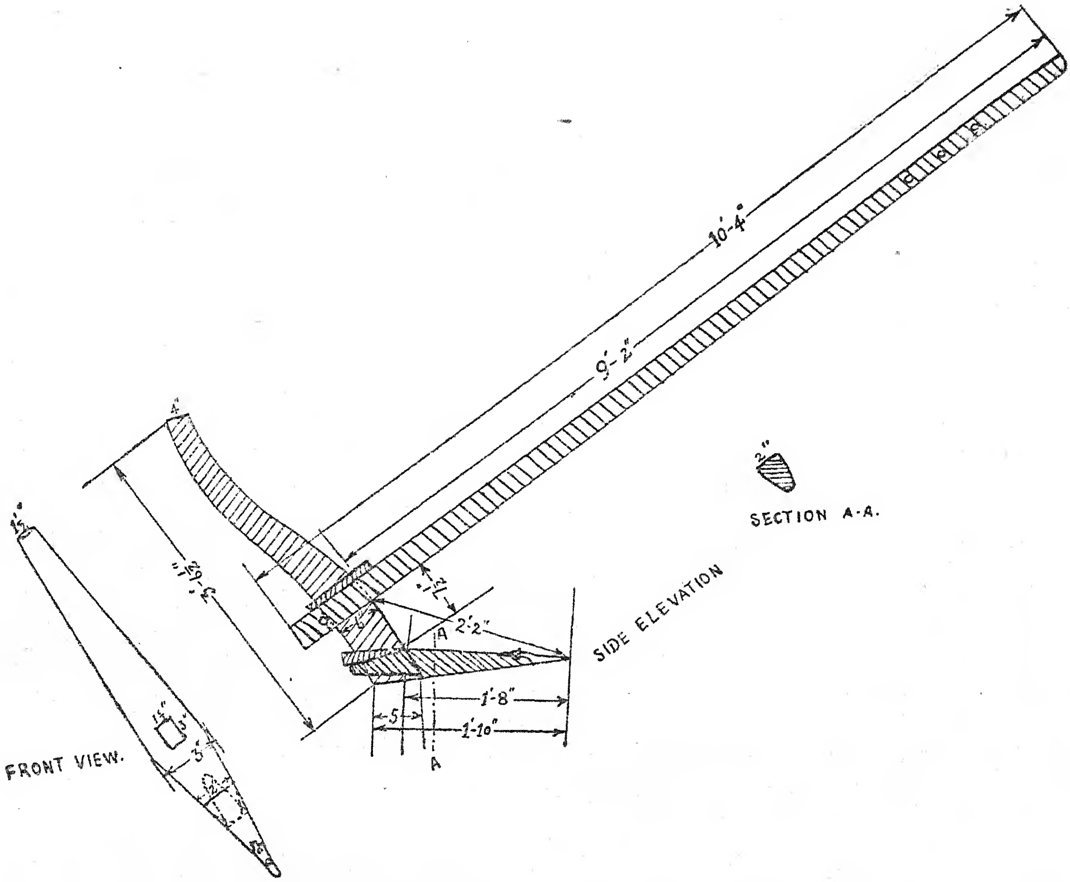


Fig. 5. Country plough, Indore

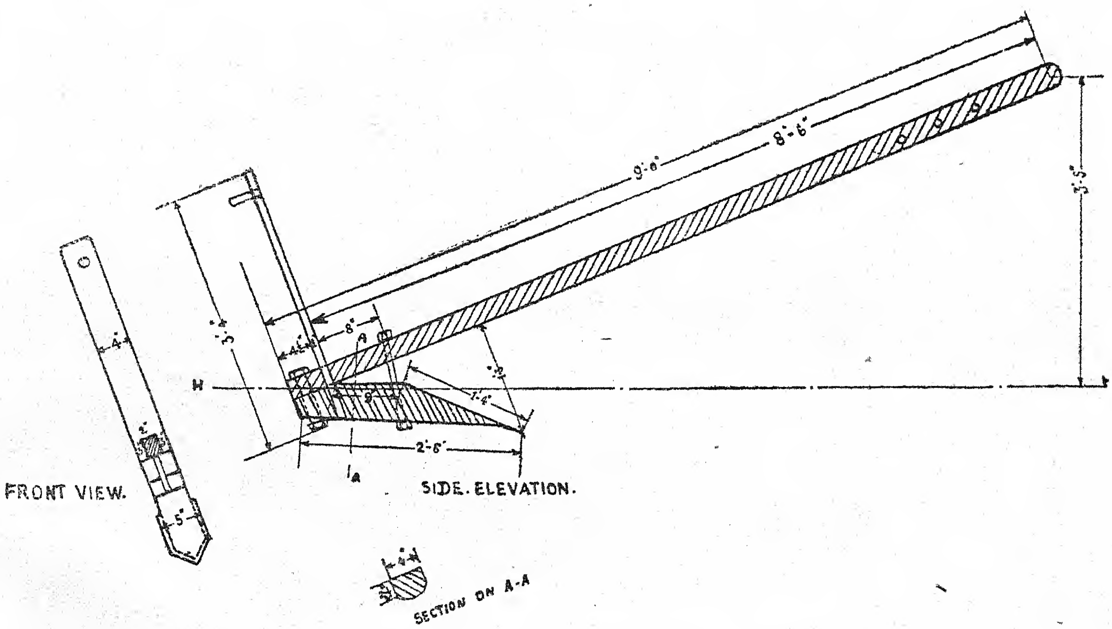


Fig. 6. Sarkar plough, Sind

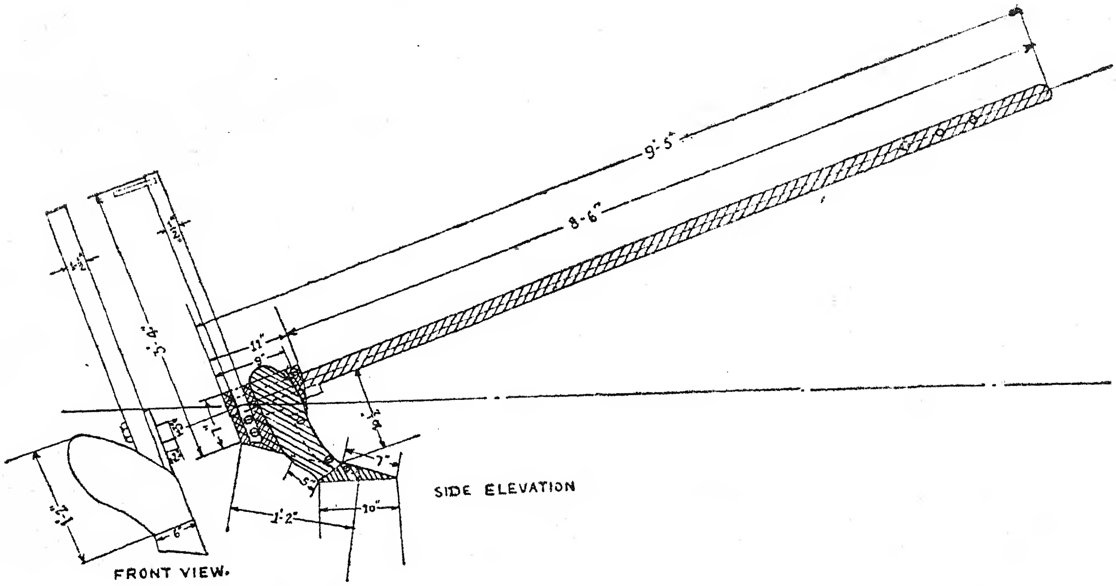


Fig. 7. Kannar plough, Sind

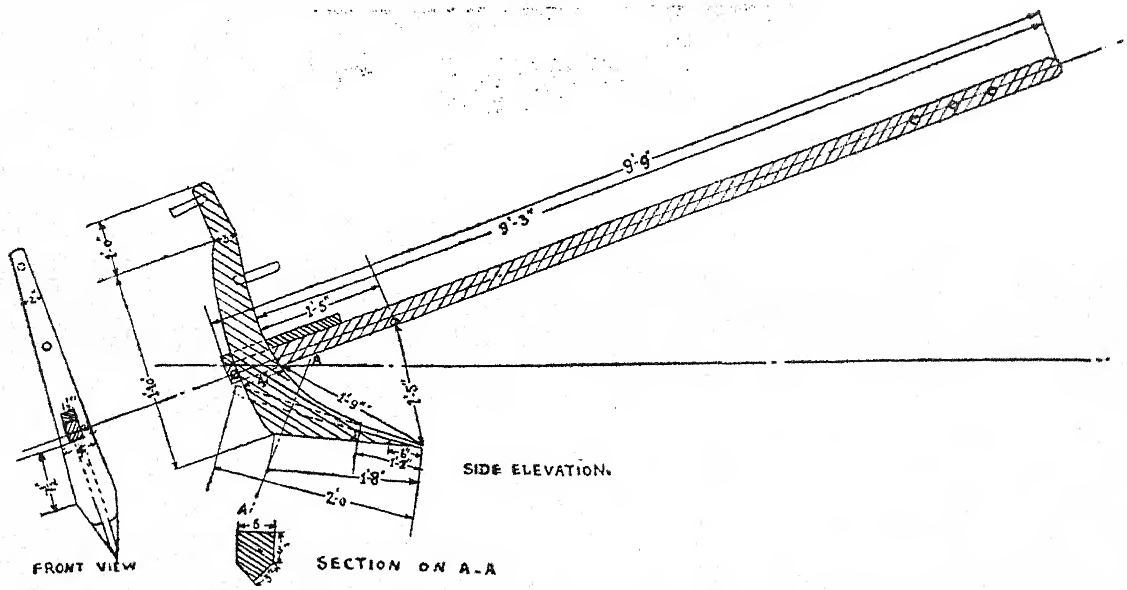


Fig. 8. Native plough, Sind

20 in. and up to its intersection with the beam is 23 in. The angle which the wedge makes with the body and beam are 140° and 46·8° respectively. The face angle of the wedge is 20°. The length of the share is 24 in. and the weight of the plough is 35·4 lb. This plough is used throughout Sind province in dry and wet tracts. Other conditions are similar to that of Sarkar and Kannar ploughs.

(9) *Country plough* (*N.-W. F. P.*). The dimensional diagram is given in Fig. 9. The wedge and body are made in one piece. The whole piece is a crude irregularly bent wood with irregular shape, one end of which is used as body and the other end is chipped to form the wedge. The beam is made from three curved pieces and the total length of the beam is 11 ft. 7 in. The length of wedge up to the beam is 11 in. An iron rectangular plate with a conical pointer is used as a coulter. The length of the share is 12 in. and projects 5 in. beyond the wedge. The weight of the plough is 47·8 lb. This plough is used all over N.-W. F. Province and is worked by camels. This plough is similar to Sarkar Sind excepting the beam and share. The share is very pointed and the beam is curved in this case.

(10) *Country plough, Karnal* (*Punjab*). The dimensional diagram is given in Fig. 10. The wedge and body are made in two pieces and assembled together in such a way that they appear to have been made in one piece. The beam is fixed to the body at a distance of 6½ in. from the inner bend between body and wedge. The beam is of rectangular cross-section 3 in. × 4 in. and its length is 10 ft. 10 in. The body and the handle are made in one piece and the width and the

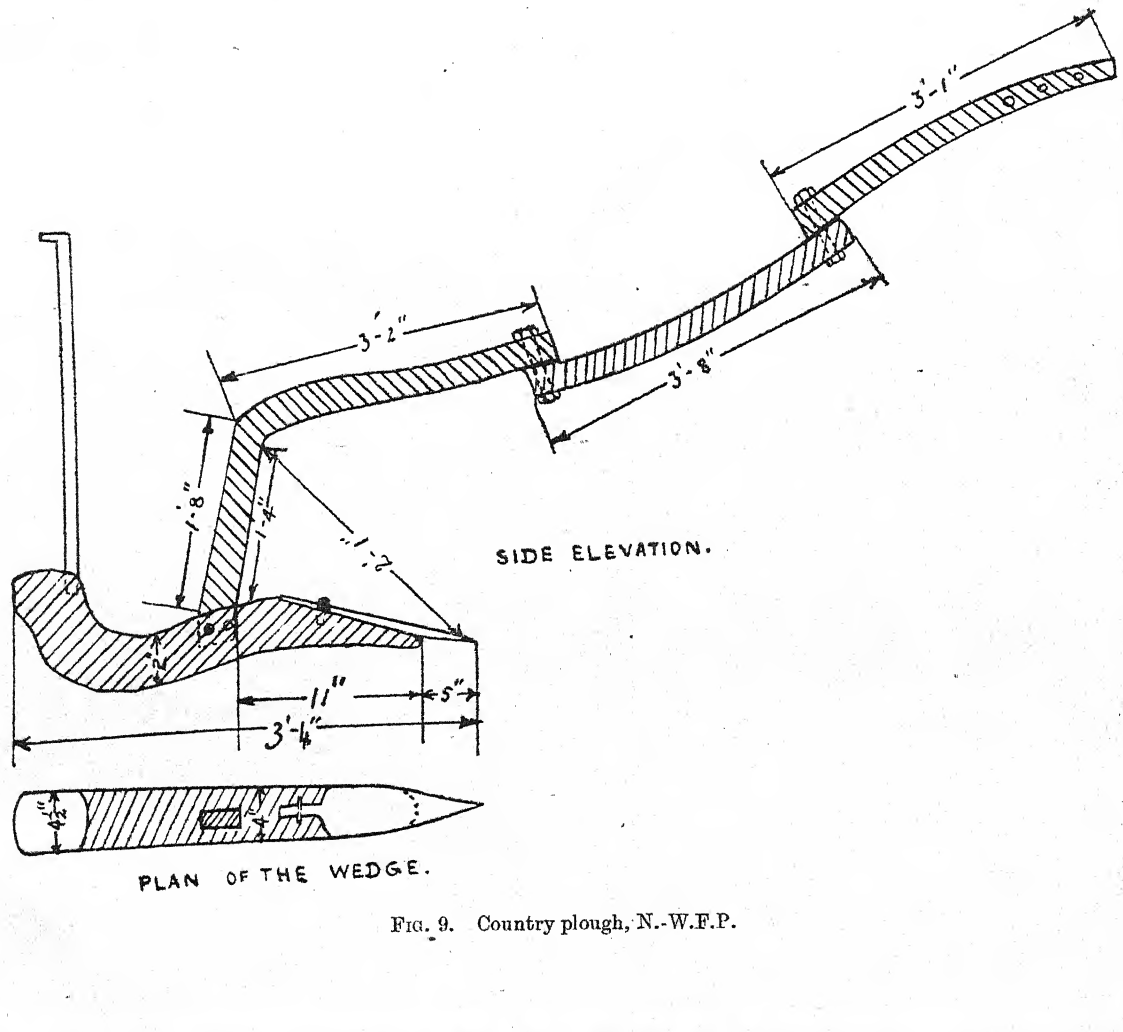


Fig. 9. Country plough, N.-W.F.P.

thickness of the body at the place where the beam is fixed to it are 6 in. and 3 in. respectively. The wedge has two shapes. Up to 14 in. from the pointed end it is a solid with a thin segmental cross-section. The flat face is protected by an iron frame and faces upwards. The remaining length of the wedge is a solid with a slight sectral cross-section, the curved surface facing downwards. The length of the wedge up to the body is 22 in. and up to its intersection with the beam is 28 in. The length of the share is 28 in. The face angle of the wedge is 31·7° and the angles which the wedge makes with the body and beam are 145° and 44·5° respectively. The weight of the plough is 51·6 lb. This plough is used in soils varying from loam to clay in Karnal district. The crops generally grown are wheat, gram, barley, *toria*, *sarson*, sugarcane, cotton, rice, maize, *jowar* and chillies. The ploughing is done after irrigation if there is no rain, the average depth of ploughing is 3 in. to 4 in. at first ploughing. It is used in both rainfed and irrigated areas. The average monthly rainfall is as follows: January = 0·59 in., February = 0·45 in., March = 0·52 in., April = 0·33 in., May = 0·63 in., June = 1·27 in., July = 4·24 in., August = 5·43 in., September = 4·78 in., October = 0·84 in., November = 0·11 in., and December = 0·43 in. A pair of Hariana or Hissar bullocks with a live weight between 950 to 1148 lb., height of 4 ft. $11\frac{1}{2}$ in. and with an average length 4 ft. 5 in. each is used to work this plough.

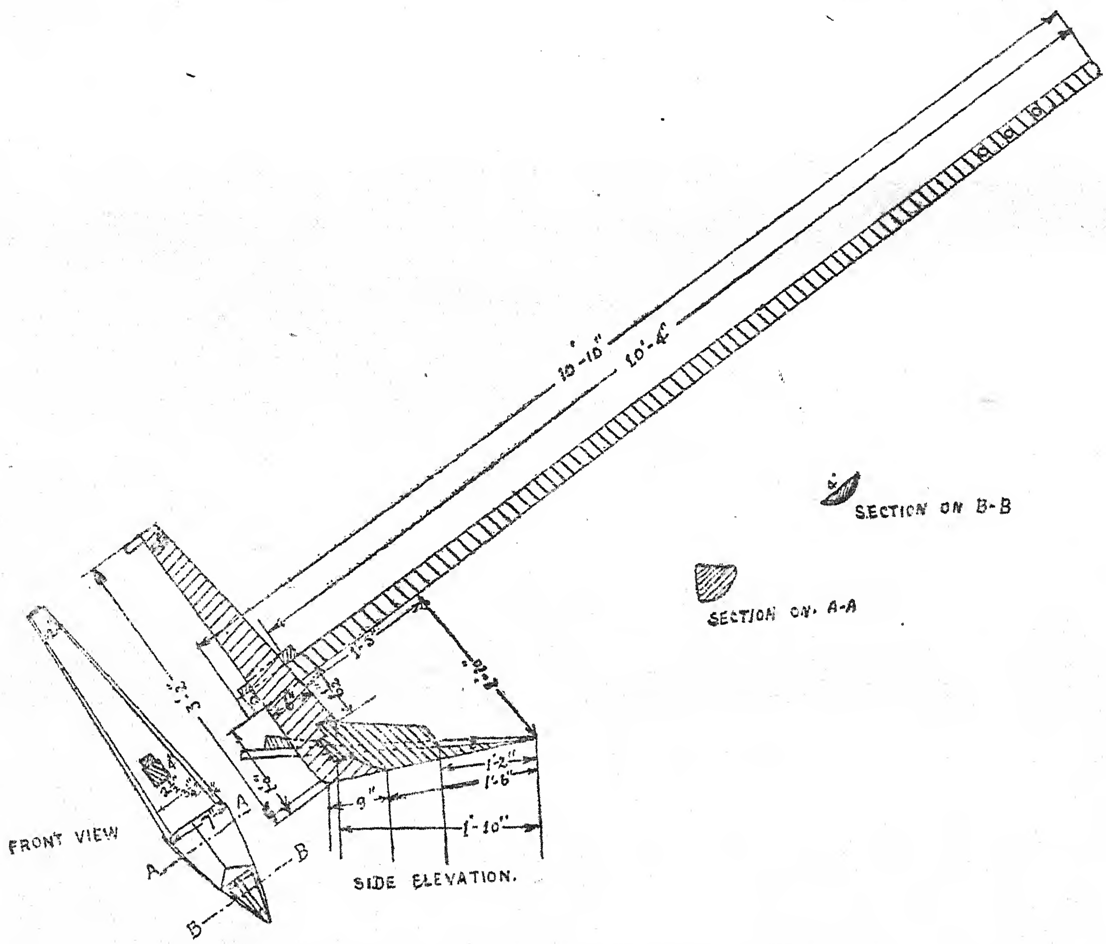


FIG. 10. Country plough, Karnal (Punjab)

(11) *Local plough, Delhi.* The dimensional diagram is given in Fig. 11. The wedge and body are made in two parts with different materials. The beam is fixed to the body at a distance of 11 in. from the place where the wedge is fixed to the body. It is of rectangular cross-section 2 in. × 4 in. and its length is 9 ft. 11 in. The body and handle are made in one piece and form a conical solid with irregular cross-sections at different places. The maximum thickness of the body just below the place where the beam is fixed to it is 5 in. The wedge is a triangular iron plate of about $\frac{3}{8}$ in. thickness with sides 7 in., 7 in. and 6 in. It is fixed to the body with the help of cotters. Its length up to its intersection with the beam is 25 in. The face angle of the wedge is 40° and the angles which the wedge makes with the body and beam are 150° and 41·3° respectively. The length of the share is 25 in. The weight of the plough is 59·7 lb. This plough is used in soils varying from sandy to clay loam and sometimes in shallow rocky soils of Delhi province. The crops generally grown are, wheat, gram, barley, *jowar*, sugarcane, cotton, pulses and vegetables. Ploughing is usually done to a depth of $2\frac{1}{2}$ in. to 6 in. immediately after the first monsoon shower for *kharif* and immediately after *kharif* harvest for *rabi* season. It is used in both rainfed and irrigated tracts. The average monthly rainfall is as follows: January = 1·04 in., February = 0·76 in., March = 0·52 in., April = 0·39 in., May = 0·58 in., June = 2·99 in., July = 7·53 in., August = 7·42 in., September = 4·78 in., October = 0·32 in., November = 0·11 in., and December = 0·40 in. A pair of Hariana bullocks with a live weight of about 800 to 900 lb. each is used to work this plough.

(12) *Country plough, Aligarh (U. P.)* The dimensional diagram is given in Fig. 12. The

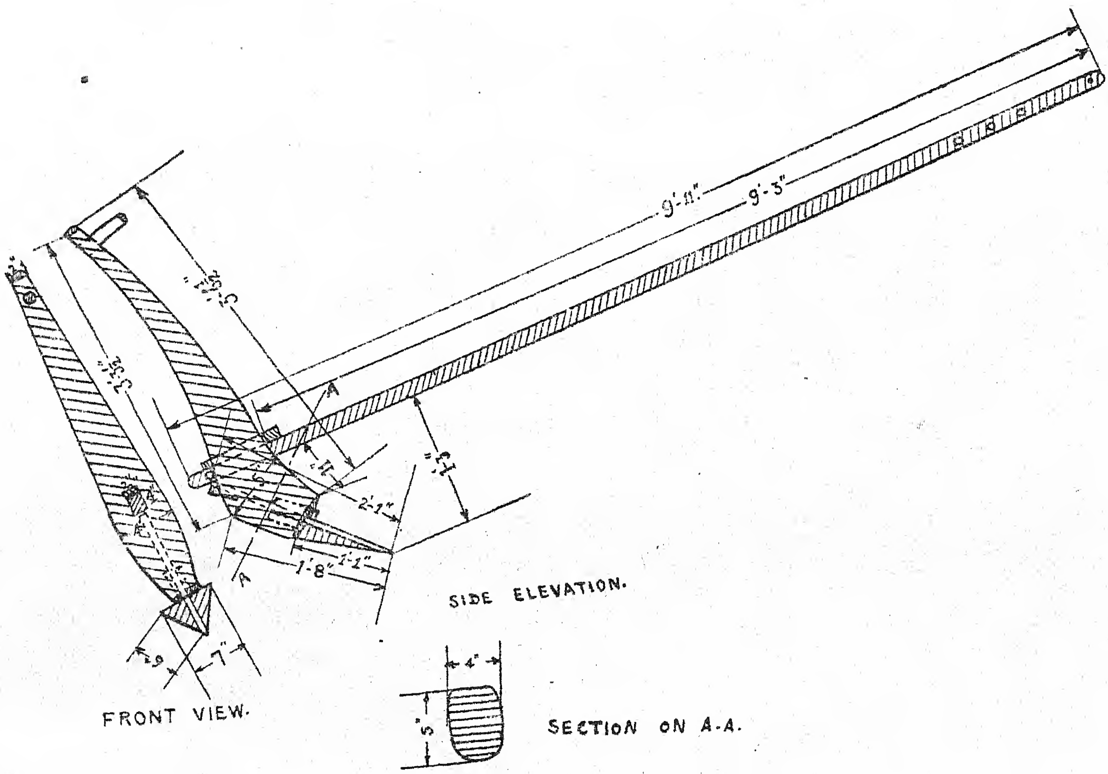


FIG. 11. Local plough, Delhi

wedge and body are made in two parts. The beam is fixed to the body at a distance of 5 in. from the inner bend between wedge and body. It is of rectangular cross-section 2 in. × 3 in. very near the body and tapers with a gradually decreasing section, its length being 9 ft. 5 in. The body and handle are made in one piece. The thickness and the width of the body at the place where the beam is fixed to it are 5 in. and $3\frac{1}{2}$ in. respectively. The wedge is a pyramid of triangular cross-section having the sides at maximum section, 5 in., 5 in. and 6 in. ; and the vertex facing downwards. The length of the wedge up to the body is 18 in. and up to the intersection with the beam is 29 in. The face angle of the wedge is 16·8° and the angles which the wedge makes with body and beam are 140° and 44·4° respectively. The length of share is 10 in. The weight of the plough is 29·2 lb. This plough is used in soils varying from light to heavy loam of Aligarh and Bulandshahr districts. The crops generally grown are wheat, cotton, sugarcane, *jowar*, pulses, gram and oilseeds. Generally at the time of ploughing the soil does not contain much moisture and at times it is dry even. The depth of ploughing is usually 3 in. to 4 in. and the plough is used in both rainfed and irrigated tracts. The average monthly rainfall is as follows : January = 1·11 in., February = 0·48 in., March = 0·58 in., April = 1·14 in., May = 0·00 in., June = 1·04 in., July = 9·58 in., August = 4·06 in., September = 10·97 in., October = 0·00 in., November = 0·00 in., and December = 2·00 in. A pair of Hariana or Hissar or local bullocks with live weight 800 to 900 lb. and with a height 3 ft. 8 in. each is used to work this plough.

(13) *Country plough, Jhansi* (*U. P.*). The dimensional diagram is given in Fig 13. The wedge and body are made in one piece. The beam is fixed to the body at a distance of 2 in. from the inner bend. The beam is of rectangular cross-section 2 in. × 4 in. and is straight to a length of 2 ft. from the body, the remaining length being slightly curved as shown in the Fig. The total length of the beam is 7 ft. 10 in. The body is of rectangular section 4 in. × 5 in. A separate handle is fixed to the beam at the back of body. The wedge is a solid having a segmental cross-section with the curved face facing downwards. Its length up to the body is 26 in. and up to its intersection with the beam is 30 in. The face angle of the wedge is 20° and the angle which the wedge makes with the body is 145°. The length of the share is 14 in. and the weight of the plough is 44·1 lb.

(14) *Country plough, Bareilly No. 1* (*U. P.*) The dimensional diagram is given in Fig. 14. This model is quite different from all the others. The wedge and body are made in two parts. The beam is fixed to the body at a distance of 6 in. from the inner bend, and is of rectangular cross-section $1\frac{1}{2}$ in. × 3 in., its length being 8 ft. 9 in. The body and handle are made in one piece and the body is a trapezoidal solid. The wedge is made of a very small piece of wood, and the share which is comparatively thicker and longer acts as a wedge. The length of wedge is very small and the angles which it makes with the body and beam are 135° and 33·05° respectively. The length of the share is 18 in., and the weight of the plough is 24·2 lb. This plough is used in soils varying from sandy to loam of Bareilly district. The crops generally grown are sugarcane, paddy, maize, *jowar*, *rahar*, wheat, barley, gram, and pulses. The ploughing is done both in dry and moist conditions and to a depth of 3 in. at the first ploughing . It is used in both irrigated and rainfed tracts. The average monthly rainfall is as follows : January = 1·01 in., February = 0·92 in., March = 0·68 in., April = 0·31 in., May = 0·33 in., June = 5·14 in., July = 10·97 in., August = 12·27 in., September = 7·47 in., October = 1·19 in., November =0·23 in., and December =0·33 in. A pair of Ponwar bullocks with a live weight 740 to 850 lb. each is used to work this plough.

(15) *Country plough, Bareilly No. 2* (*U. P.*). The dimensional diagram is given in Fig. 15. The wedge and the body are made in two pieces and the construction of this plough is similar to that of Dohad and Indore except in angles and dimensions of the parts. The beam is fixed to the body at a distance of 3 in. from the inner bend. It is of rectangular cross-section 2 in. × $2\frac{1}{2}$ in., its length being 9 ft. 1 in. The body and handle are made in one piece. The wedge is very narrow and similar to that of Dohad. The length of the wedge up to the body is $22\frac{1}{2}$ in. and up to its intersection with the beam is 32 in. The face angle of the wedge is 6·8° and the angles which the wedge makes with the body and beam are 140° and 40° respectively. The weight of the plough is 25·1 lb. Other conditions and particulars are similar to that of No. 14.

(16) *Country plough, Kakori* (*U. P.*). The dimensional diagram is given in Fig. 16. This model is very similar to that of Bareilly No. 1. Other particulars and conditions under which it is used are similar to that of Bareilly No. 1.

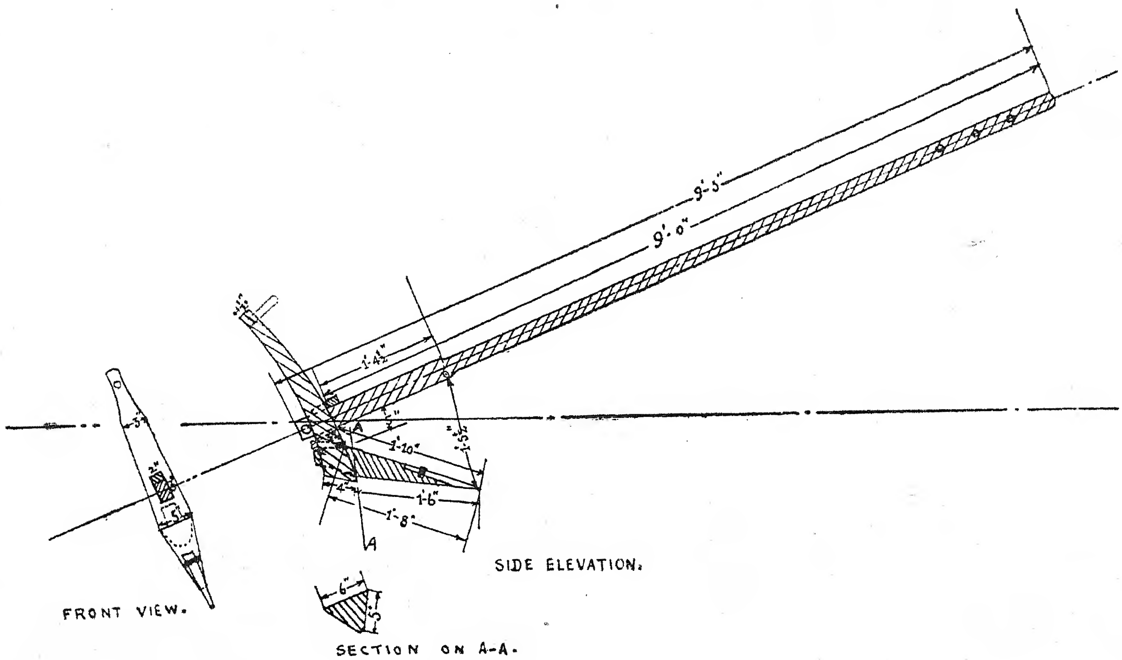


Fig. 12. Country plough, Aligarh (U.P.)

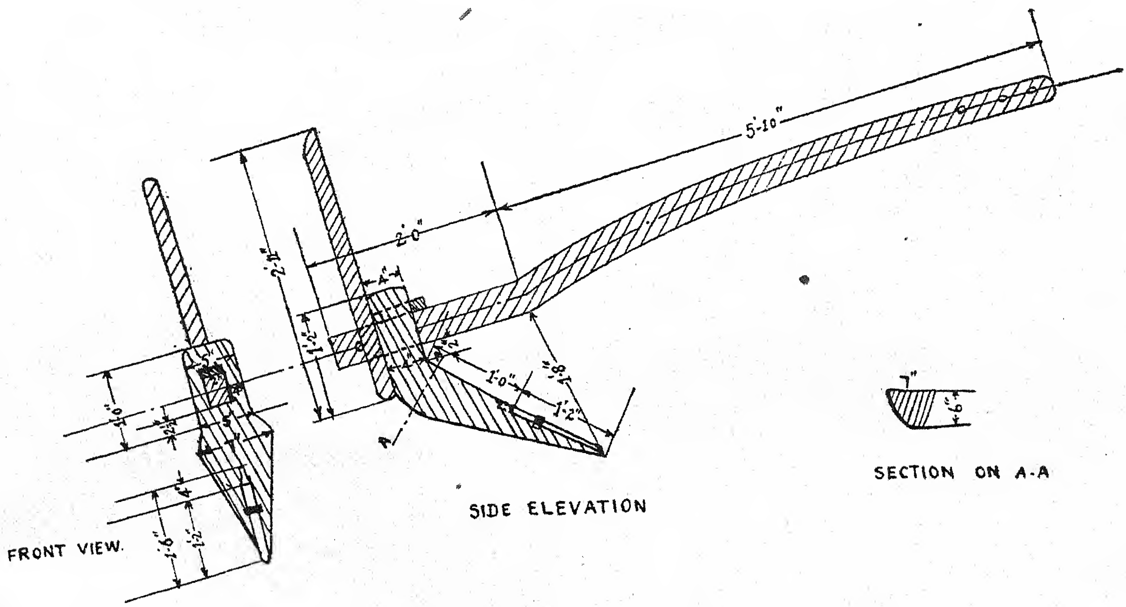


Fig. 13. Country plough, Jhansi (U.P.)

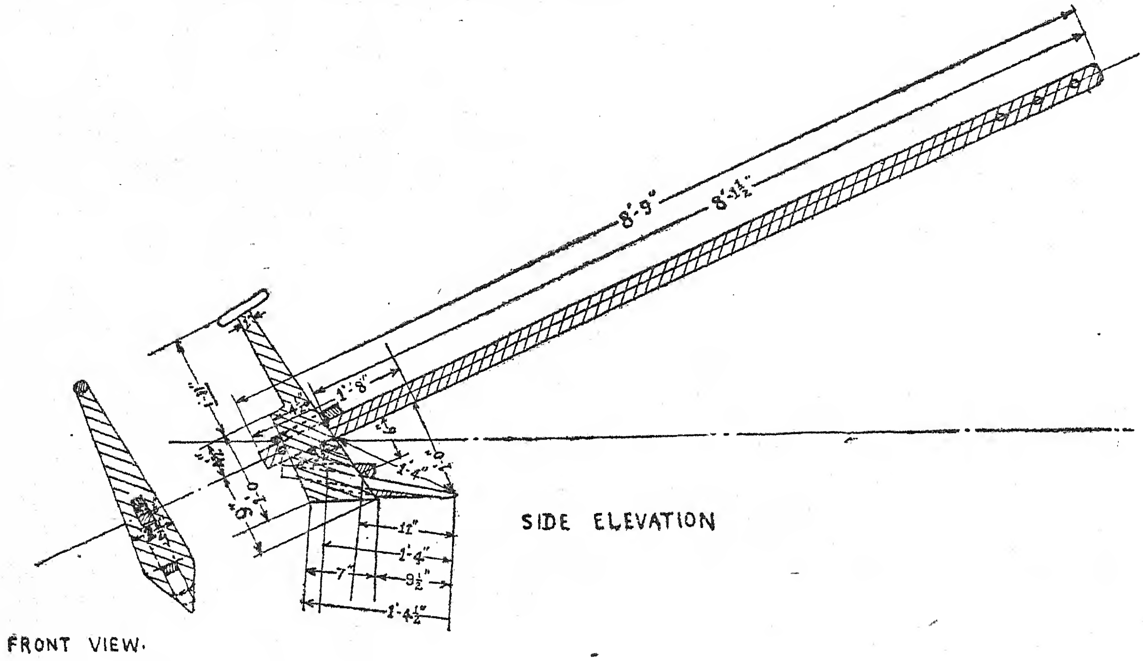


Fig. 14. Country plough, Bareilly No. 1 (U.P.)

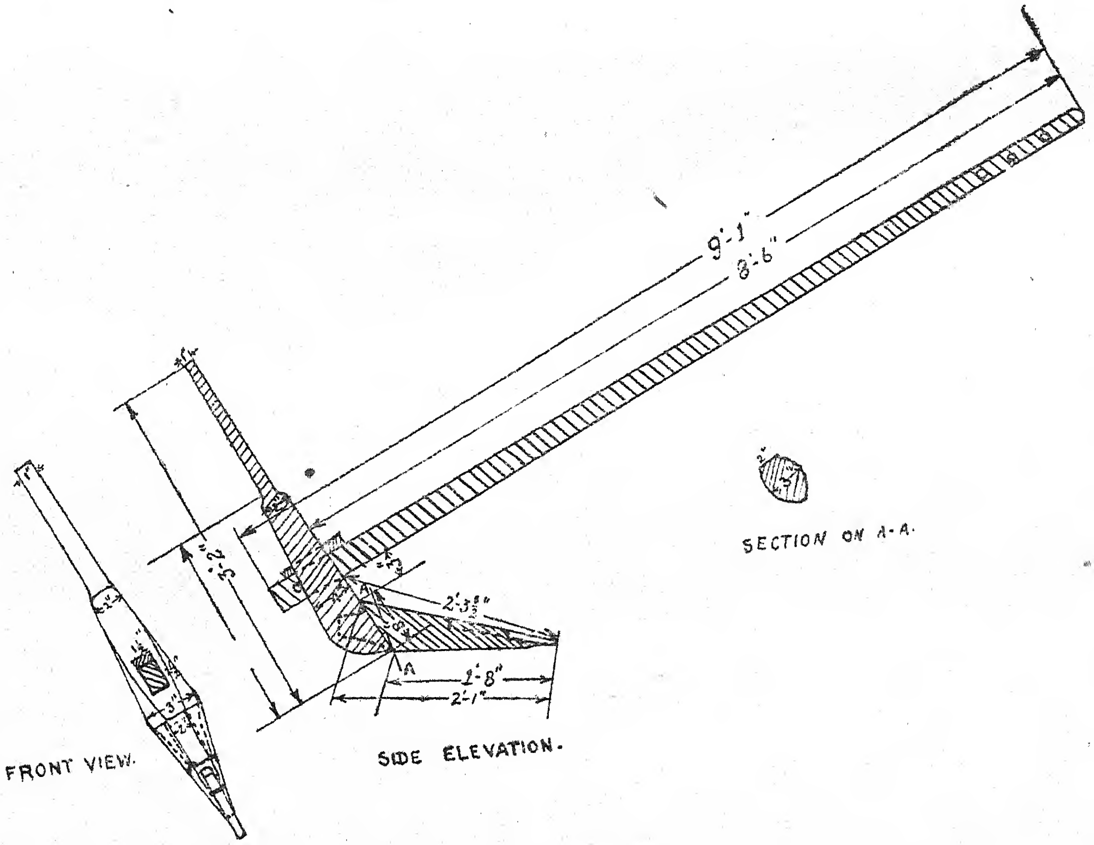


Fig. 15. Country plough, Bareilly No. 2 (U.P.)

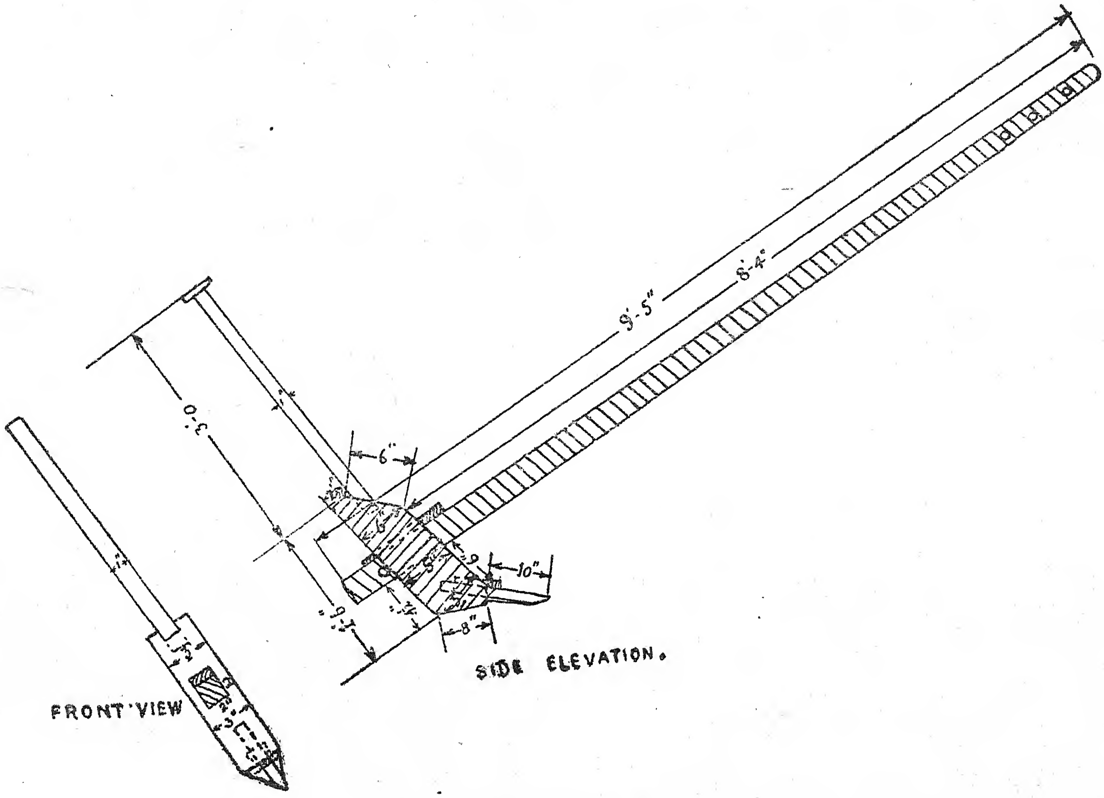


FIG. 16. Country plough, Kakori (U.P.)

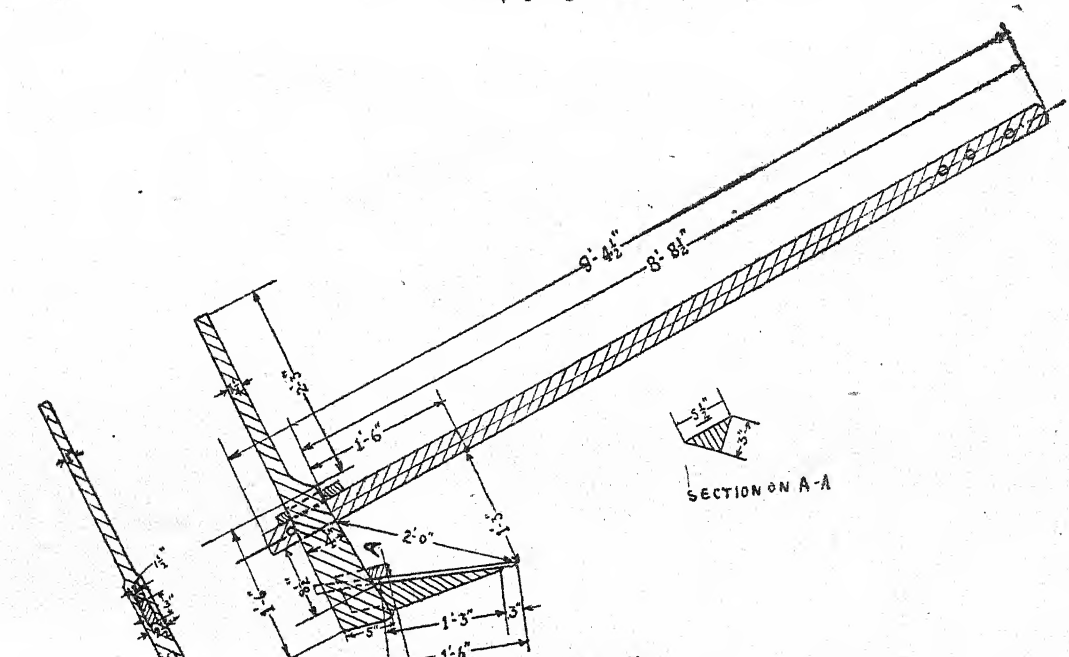


FIG. 17. Wooden plough, Gorakhpur No. 1 (U.P.)

(17) *Wooden plough, Gorakhpur No. 1 (U. P.)* The dimensional diagram is given in Fig. 17. The wedge and body are made in two pieces. The beam is fixed to the body at a distance $8\frac{1}{2}$ in. from inner bend. It is of rectangular cross-section $1\frac{1}{2}$ in. × 2 in., its length being 9 ft. $4\frac{1}{2}$ in. The body and handle are made in one piece and the thickness and width of the body at the place where the beam is fixed to it are 4 in. and 3 in. respectively. The wedge is a pyramid of triangular cross-section with the sides at maximum section 3 in., 3 in. and $5\frac{1}{2}$ in., the vertex facing downwards and $5\frac{1}{2}$ in. side facing upwards. The length of the wedge up to the body is 15 in. and up to its intersection with the beam is 28 in. The face angle of the wedge is 21·2° and the angles which it makes with the body and beam are 131° and 45° respectively. The length of the share is 24 in. The weight of the plough is 22·6 lb., and this plough is well known locally by the name *Khopidar*. This plough is used in soils varying from light sandy to heavy clay of Gorakhpur and Bahraich districts. The crops generally grown are sugarcane, paddy, wheat, pulses, maize and oilseeds. This plough is usually used for second ploughing in heavy soils and used for all ploughings in the light soils to a depth of 6 in. to 7 in. This plough is used in both rainfed and irrigated tracts. The average monthly rainfall is as follows: January = 0·67 in., February = 0·60 in., March = 0·39 in., April = 0·40 in., May = 1·47 in., June = 7·41 in., July = 13·43 in., August = 13·99 in., September = 8·07 in., October = 3·45 in., November = 0·17 in., and December = 0·14 in. A pair of local bullocks with a live weight of 500 lb. and 3 ft. 6 in. height each is used to work this plough.

(18) Desi *plough, Gorakhpur No. 2 (U. P.)*. The dimensional diagram is given in Fig. 18. This design is similar to that of wooden plough Gorakhpur No. 1 except in the cross-section of wedge and dimensions of some parts. The wedge is a pyramid of pentagonal cross-section with sides $6\frac{1}{2}$ in., $\frac{3}{4}$ in., 3 in., 3 in. and $\frac{3}{4}$ in. at maximum section, one vertex faces downwards. The length of the share is 24 in. and other particulars and conditions are similar to that of Wooden Plough No. 1.

(19) Desi *plough, Gorakhpur No. 3 (U. P.)*. The dimensional diagram is given in Fig. 19. The wedge and body are made in one piece. The beam is fixed to the body at a distance of 1 in. from the inner bend. It is of a rectangular cross-section 2 in. × 3 in., its length being 9 ft. The wedge is a pyramid of triangular cross-section having the sides 8 in., $4\frac{1}{2}$ in. and $4\frac{1}{2}$ in. at maximum section, with the vertex facing upwards. The length of the wedge up to the body is 21 in. and up to its intersection is 27 in. The face angle of the wedge is 23·2° and the angle which the wedge makes with the body and beam are 143° and 49·1° respectively. The length of the share is 6 in. and a separate handle is fixed to the beam at the back of the body. The weight of the plough is 23·6 lb. This plough is known locally by the name *Khutehra* (i.e. lighter) and is made of *babul* wood. It is used in clay soils of Balia and Azamgarh districts for first ploughing to a depth of 2 in. to 3 in. In other respects and conditions it is similar to No. 17.

(20) Desi *plough, Gorakhpur (U.P.)*. This design is similar to that of No. 3, except in the length of the wedge and of weight. This plough is known locally by the name *Nauhara* and is used in Balia and Azamgarh districts.

(21) *Local plough, Chotanagpur (Bihar)*. The dimensional diagram is given in Fig. 20. The body and the wedge are made in a single piece. There is no bend between body and wedge. The beam is fixed to the wedge and the body is of rectangular cross-section 2 in. × 3 in., its length being 9 ft. 2 in. The body is a rectangular solid with a cross-section 8 in. × $5\frac{1}{2}$ in. A separate handle is fixed to it. The wedge is a frustrum of four sides with cross-section 8 in. × 5 in. × 1 in. × 5 in. at maximum section and $5\frac{1}{2}$ in. × 4 in. × 1 in. × 4 in. at the penetrating end, the 1 in. side faces upwards. The wedge is chipped to form a slope at the penetrating edge. The length of the wedge is 21 in. The length of the share is 12 in. and protrudes 6 in. from the wedge. The angle which the wedge makes with the beam is 46·2°. The weight of the plough is 34·3 lb. This plough is used in soils varying from rocky to good soils of Chotanagpur. The crops generally grown are paddy, maize, *rahar*, gram, *gondli*, *marua* and cotton. The ploughing is done to a depth 1 in. to 4 in. when there is sufficient moisture which makes the soil suitable for ploughing. It is used only in rainfed areas. The average monthly rainfall is as follows: January = 0·35 in., February = 0·68 in., March = 0·41 in., April = 0·58 in., May = 1·47 in., June = 7·66 in., July = 11·48 in., August = 13·70 in., September = 8·39 in., October = 1·80 in., November = 0·41 in., and December = 0·21 in. A pair of bullocks with a live weight 650 lb., height 3 ft. 9 in. and girth 2 ft. 10 in. each or a pair of buffaloes with a live weight

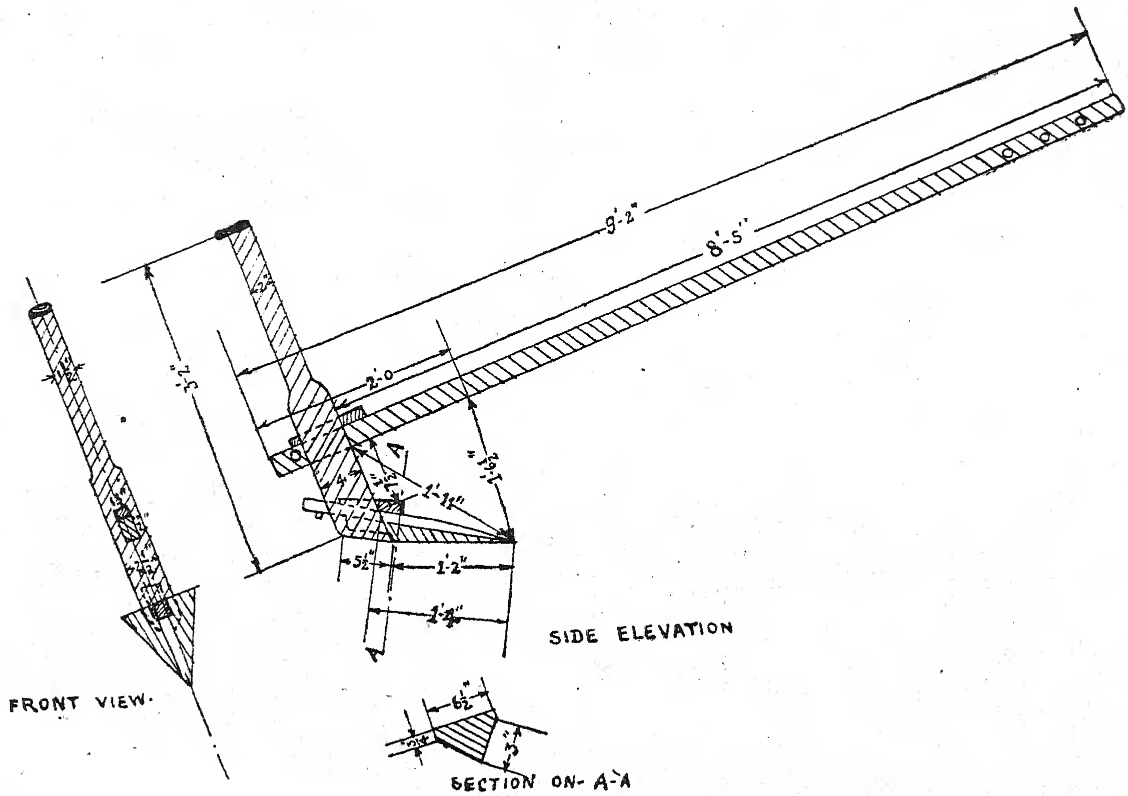


FIG. 18. *Desi* plough, Gorakhpur No. 2 (U.P.)

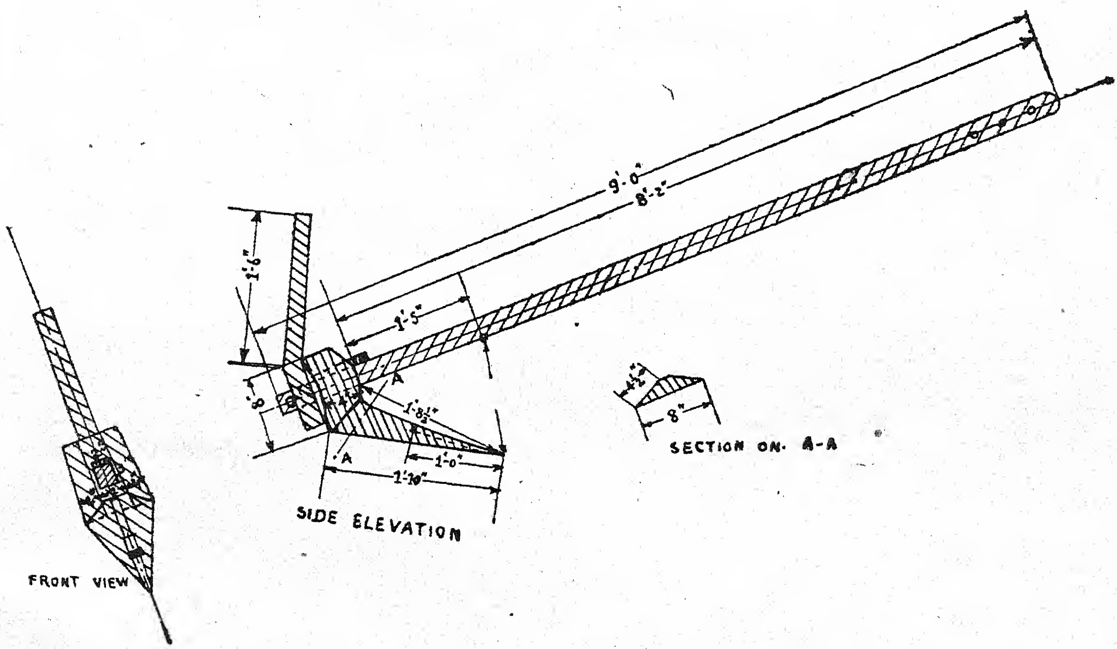


FIG. 19. *Desi* plough, Gorakhpur No. 3 (U.P.)

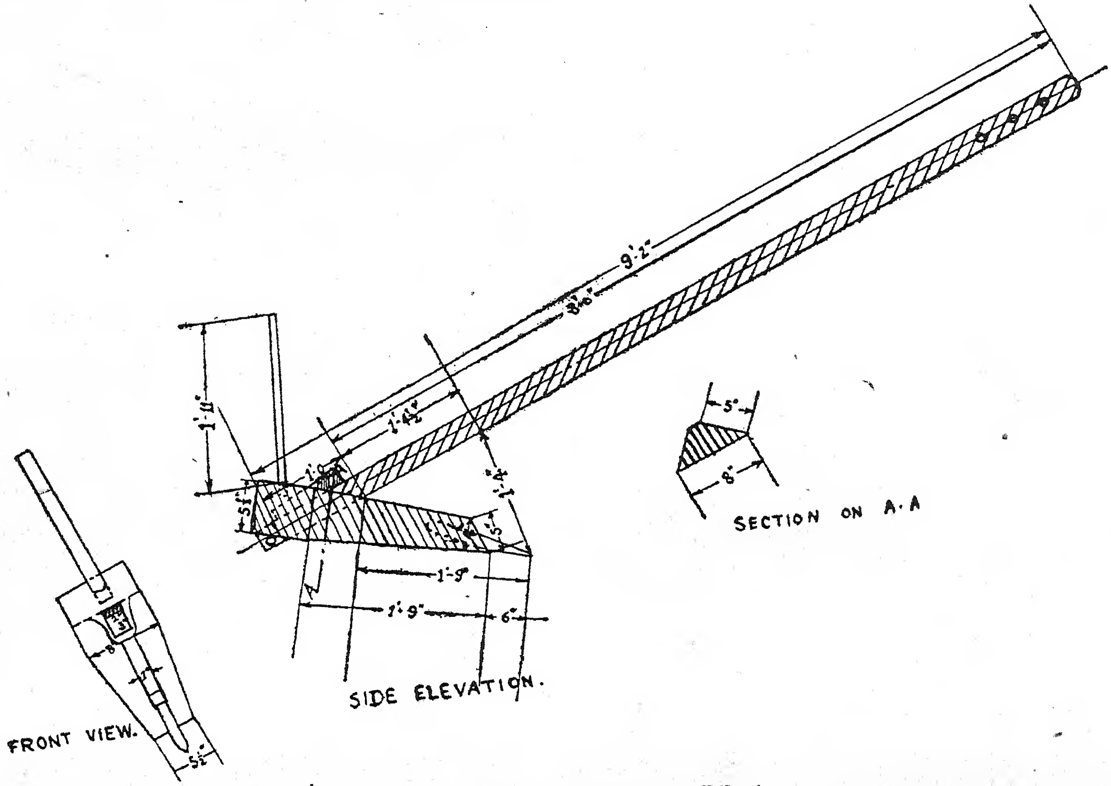


Fig. 20. Local plough, Chotanagpur (Bihar)

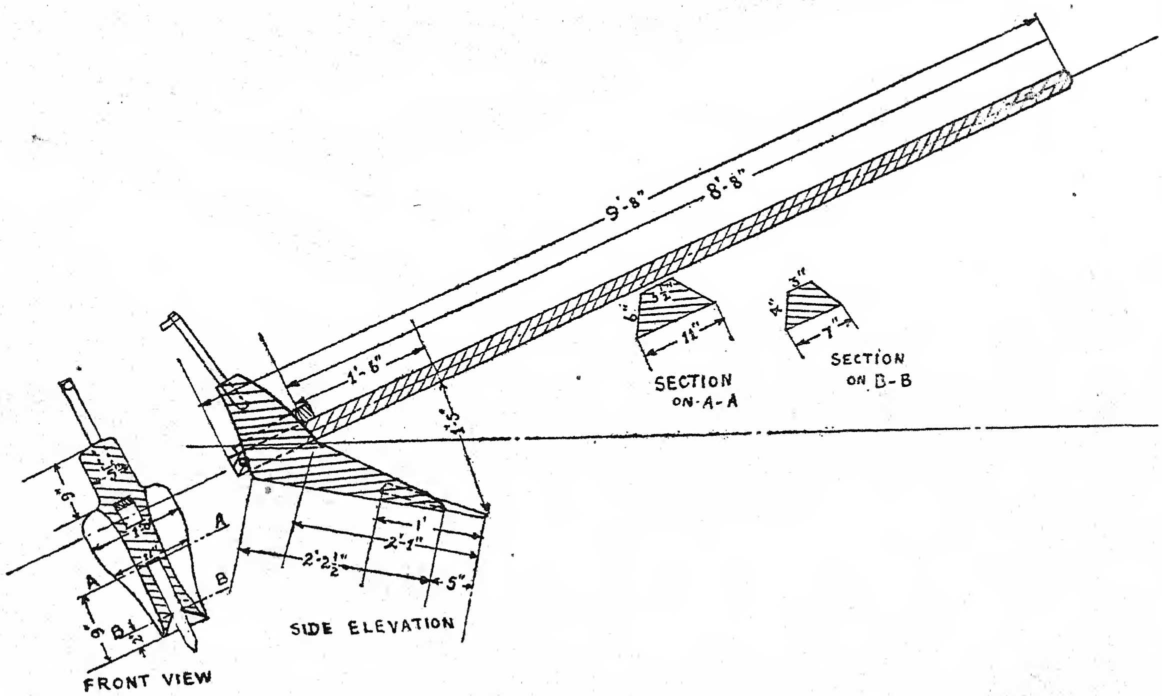


Fig. 21. Local plough, Chotanagpur, Netarhat (Bihar)

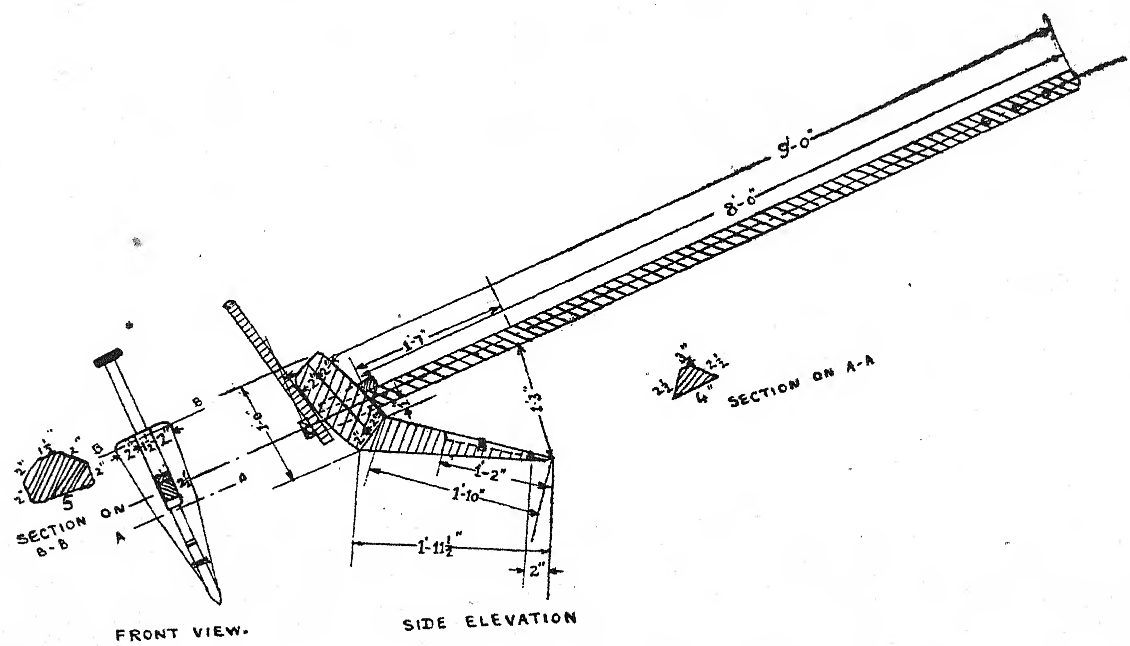


FIG. 22. Country plough, Patna (Bihar)

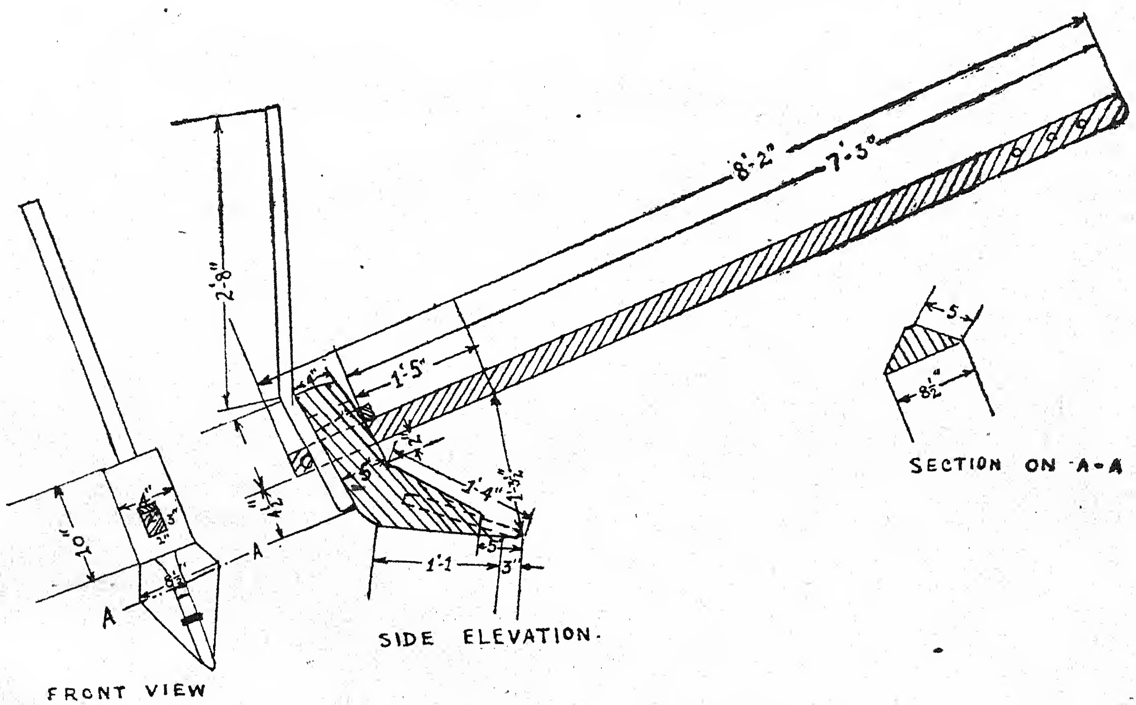


FIG. 23. Country plough, Pusa Farm (Bihar)

800 lb., height 4 ft. 4 in. and girth 3 ft. 9 in. each is used to work this plough.

(22) *Local plough, Chotanagpur, Netarhat* (*Bihar*). The dimensional diagram is given in Fig. 21. This design is similar to that of L. P. Chotanagpur (21), except that there is a slight bend between the body and the wedge. The wedge and body are made in one piece and the beam is fixed to the wedge very near the bend. The beam is of rectangular cross-section 2 in. × 3 in. and its length is 9 ft. 8 in. The wedge is a solid of trapezoidal cross-section having the sides of sections 11 in., 6 in., 3½ in., 6 in. and 7 in., 4 in., 3 in., 4 in., at maximum and minimum sections respectively. The small side faces upwards. The length of the wedge up to the body is 26½ in. The angle which the wedge makes with the beam is 48·35°. A separate handle is fixed to the body. The length of the share is 12 in. and protrudes 5 in. out of the wedge. The weight of the plough is 41·8 lb. and is used in soils varying from rocky to good soils of Bishnupur and Mohwadar Thanas in Netarhat plateau. Other conditions and particulars are similar to No. 21.

(23) *Country plough, Patna* (*Bihar*). The dimensional diagram is given in Fig. 22. The wedge and body are made in one piece. The beam is fixed to the body at a distance of 1 in. near the bend. It is of rectangular cross-section 1½ in. × 2½ in. and its length is 9 ft. The body is a solid of a trapezoidal cross-section and a separate handle is fixed to the beam at the back of the body. The wedge is a pyramid of triangular cross-section having the sides 6 in. × 4 in. × 4 in. at maximum section. The vertex of the section is slightly flattened and faces upwards. The length of the wedge up to the body is 22½ in. and up to its intersection with the beam is 28 in. The face angle of the wedge is 20° and the angles which the wedge makes with the body and beam are 150° and 39·5° respectively. The length of the share is 14 in. and the weight of the plough is 24·8 lb. This plough is used in all kinds of soils in Patna district. The crops generally grown are paddy, *rahar*, sugarcane, wheat, gram, etc. The ploughing is done to a depth of 3 in. when the moisture is about 15 per cent. It is used in both rainfed and irrigated tracts and the average monthly rainfall is as follows: January = 0·53 in., February = 0·71 in., March = 0·47 in., April = 0·30 in., May = 1·67 in., June = 8·12 in., July = 11·94 in., August = 13·55 in., September = 8·33 in., October = 2·54 in., November = 0·28 in., and December = 0·09 in. A pair of country bullocks with a live weight 500 lb. each is used to work this plough.

(24) *Country plough, Pusa* (*Bihar*). The dimensional diagram of this plough is given in Fig. 23. The wedge and body are made in one piece and the beam is fixed to the body at a distance of 2 in. from the inner bend. The beam is of a rectangular cross-section 2 in. × 3 in. and its length is 8 ft. 2 in. The thickness and the width of the body at the place where the beam is fixed to it are 5 in. and 4 in. respectively. A separate handle is fixed to the beam at the back of the body. The wedge is a pyramid of triangular cross-section with the vertex slightly flattened and facing upwards. The sides of cross-section at maximum section are 8½ in., 5 in. and 5 in. The length of the wedge up to the body is 16 in. and up to its intersection with the beam is 22 in. The face angle of the wedge is 35° and the angles which the wedge makes with the body and the beam are 150° and 44·9° respectively. The length of share is 12 in. and protrudes 2 in. outside the wedge. The weight of the plough is 34·3 lb. This plough is used in soils varying from sandy to heavy loams of Muzaffarpur, Darbhanga, Saran and South Champaran districts. The crops generally grown are sugarcane, wheat, barley, maize, *rahar*, pulses and paddy. The ploughing is done to a depth of 3 in. when the moisture is about 20 per cent and the plough is used for puddling paddy fields. It is used mostly in rainfed areas and the average monthly rainfall is as follows: January = 0·35 in., February = 0·68 in., March =0·41 in., April = 0·58 in., May = 1·47 in., June =7·66 in., July = 11·48 in., August = 13·70 in., September = 8·39 in., October = 1·80 in., November = 0·41 in., and December = 0·21 in. A pair of local bullocks with live weight 600 to 800 lb. each is used to work this plough.

(25) *Local plough, Chotanagpur, Ranchi* (*Bihar*). The dimensional diagram is given in Fig. 24. The wedge, the body and the handle are made in one piece. The beam is fixed to the body at a distance of 3 in. from the inner bend and is of rectangular section 2 in. × 3 in., its length being 6 ft. 7 in. The body is a solid trapezium in cross-section. The wedge is a pyramid of triangular cross-section having the sides 5½ in., 3 in. and 3 in. at maximum section with its vertex slightly flattened and facing upwards. The face angle of the wedge is 28° and the angles which the wedge makes with the body and beam are 150° and 39·05° respectively.

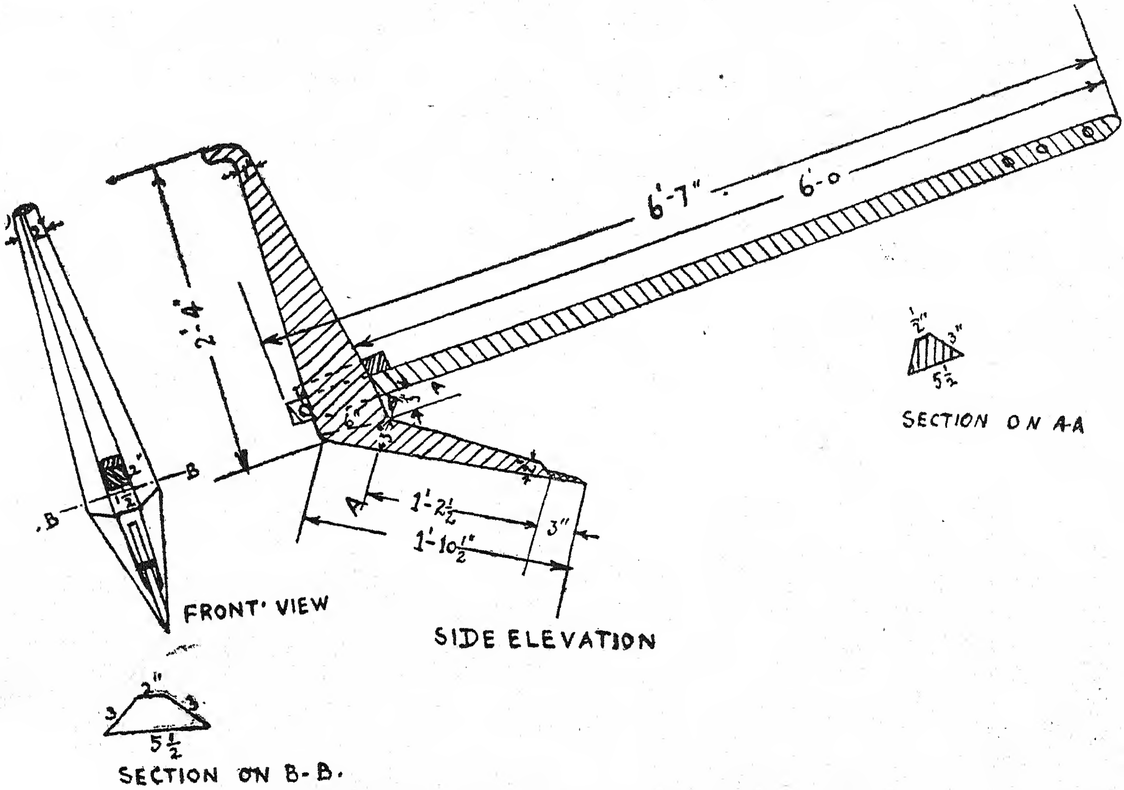


Fig. 24. Local plough, Chotanagpur, Ranchi (Bihar)

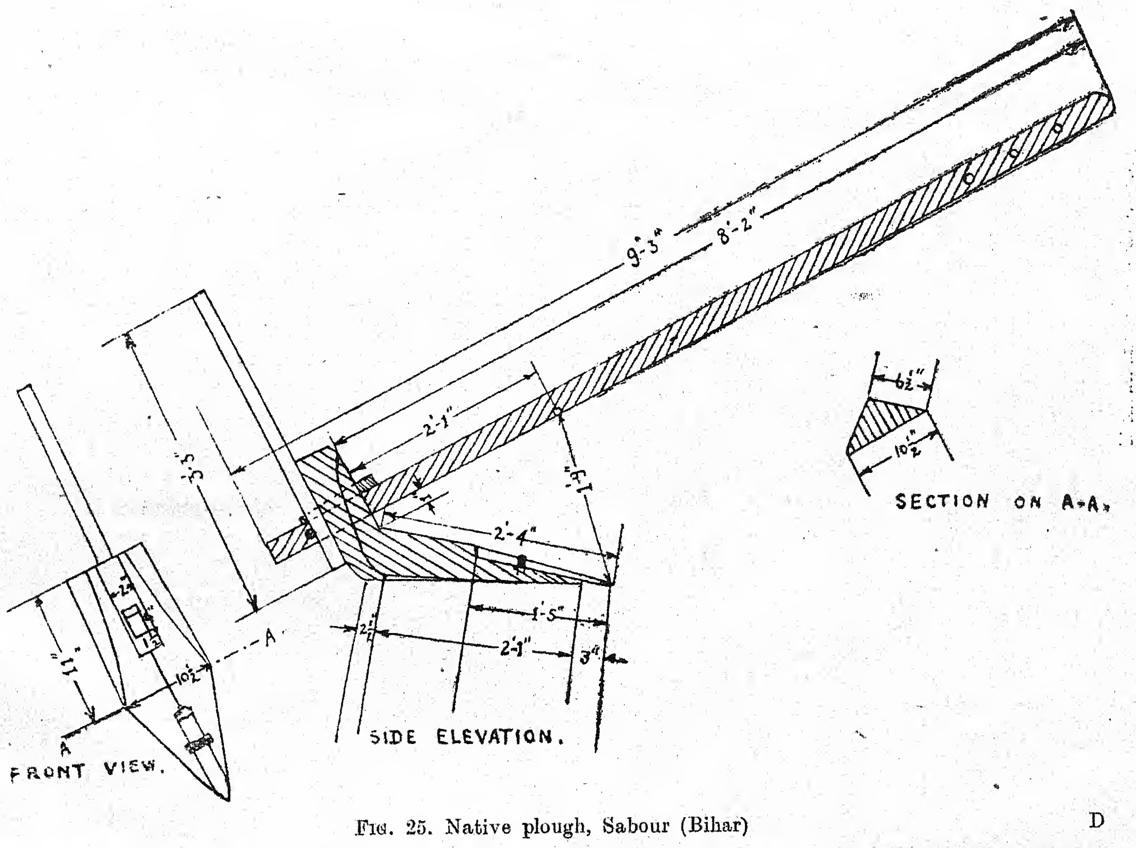


Fig. 25. Native plough, Sabour (Bihar)

The length of the wedge up to the body is 22½ in. and up to the beam is 28 in. The length of the share is 16 in. and projects 3 in. outside the wedge; and the weight of the plough is 16·4 lb. This plough is used in the soils varying from sandy loam with grit in the uplands to heavy clay in the valley or dune of Ranchi district. The crops grown generally are paddy, *rahar*, maize, pulses, barley and wheat. Ploughing is usually done after rains when the moisture is between 25 per cent to 30 per cent. In the first instance the depth of the ploughing is between 1½ in. to 3 in. and the second ploughing it is 2½ in. to 3 in. It is used in rainfed areas and the average monthly rainfall is as follows: January = 0·79 in., February = 1·60 in., March = 1·30 in., April = 0·95 in., May = 2·41 in., June = 9·68 in., July = 14·77 in., August = 13·17 in., September = 9·14 in., October = 2·84 in., November = 0·38 in., and December = 0·18 in. A pair of bullocks with live weight 330 to 410 lb. each or buffaloes with live weight 650 to 900 lb. each is used to work this plough.

(26) *Native plough, Sabour* (*Bihar*). The dimensional diagram is given in Fig. 25. The wedge and body are made in one piece. The beam is fixed to the body at a distance of 2 in. from the inner bend and is of rectangular section 1½ in. × 3 in., its length being 9 ft. 3 in. A separate handle is fixed to the beam at the back of the body. The wedge is a triangular pyramid having the sides of cross-section at its maximum 10½ in., 6½ in. and 6½ in. with the vertex facing upwards. The length of the wedge up to the body is 28 in. and up to its intersection with the beam 37 in. The face angle of the wedge is 30° and the angles which the wedge makes with body and beam are 155° and 45·5° respectively. The length of the share is 17 in. and it is thick and broad. The weight is 44·1 lb. and the plough is used in soils varying from light to heavy of Bhagalpur district and ploughing is done when the moisture percentage is very high. For puddling purpose the wedge will be made a bit narrow. In Santhal Parganas the same plough with narrow wedge is used as the animals are comparatively weak and small. The crops generally grown are paddy, maize and pulses. Ploughing is done usually to a depth of 3 in. to 4 in. It is used in rainfed areas and the average monthly rainfall is as follows: January = 0·41 in., February = 0·72 in., March = 0·37 in., April = 0·67 in., May = 3·51 in., June = 7·90 in., July = 11·13 in., August = 11·54 in., September = 8·83 in., October = 2·45 in , November = 0·33 in., and December = 0·08 in. A pair of local bullocks or buffaloes is used to work this plough.

(27) *Wooden country plough, Bankura* (*Bengal*). The dimensional diagram is given in Fig. 26. The body and wedge are made in one piece. The beam is fixed to the body at a distance of 3 in. from the inner bend between the body and wedge . It is of rectangular section 2 in. × 4 in. up to 2 ft. from the body and oval in the remaining length and its length being 8 ft. 5 in. A separate handle is fixed to the body. The wedge is a pyramid of triangular cross-section with sides 9½ in., 4 in. and 4 in. and with its vertex facing upwards. The length of the wedge up to the body is 20½ in. and up to its intersection with the beam is 28 in. The face angle of the wedge is 39° and the angles which the wedge makes with the body and beam are 135° and 41·9° respectively. A flat share is used to protect the penetrating edge. The weight of the plough is 31 lb. This plough is used in sedulary laterite soils, with full gravels of various sizes of Bankura district. Paddy is the only crop grown in this district. Ploughing is usully done to a depth from 3 in. to 4 in. It is used in waterlogged condition or when the moisture percentage is high. It is used in both rainfed and irrigated areas. The average rainfall is as follows: January = 0·19 in., February = 1·66 in., March = 0·76 in., April = 0·97 in., May = 2·77 in., June = 8·68 in., July = 11·62 in., August = 11·52 in., September = 7·01 in., October = 2·52 in., November = 0·39 in., and December = 0·12 in. A pair of bullocks with live weight of 470 lb. each is used to work this plough.

(28) *Wooden plough, Tippera* (*Bengal*). The dimensional diagram is given in Fig. 27. The body and the wedge are made in one piece. The beam is fixed to the body very near the inner bend and is of rectangular cross-section 1½ in. × 2½ in. and its length being 7 ft. 3 in. A separate handle is fixed to the beam in front of the body. The cross-section of the wedge is shown in the diagram. It will be seen that the vertex faces upwards. The length of the wedge up to the body is 23 in. and up to its intersection with the beam is 25 in. The angles which the wedge makes with the body and the beam are 130° and 40° respectively. The weight of the plough is 28 lb. This plough is used in new alluvial soil of light texture—Meghna silt in Tippera district. The crops generally grown are paddy, jute and pulses. Ploughing is usually done to a depth of 3 in. to 4 in. when the moisture is about 15 per cent to 25 per cent. It is

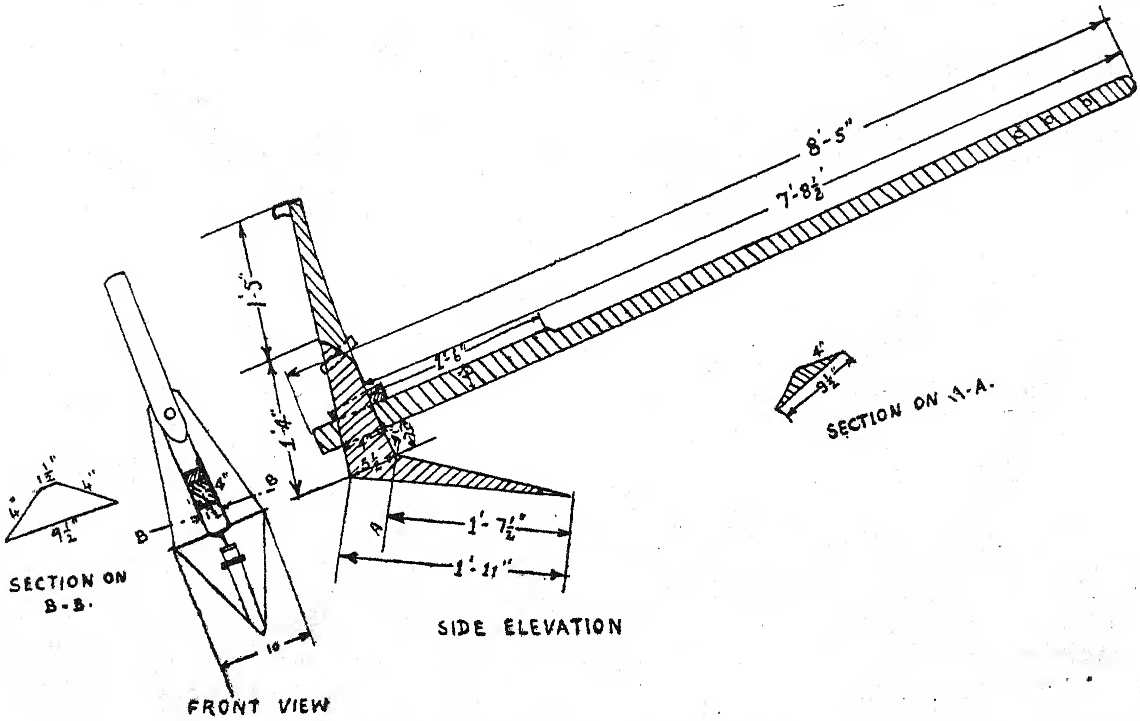


Fig. 26. Country plough, Bankura (Bengal)

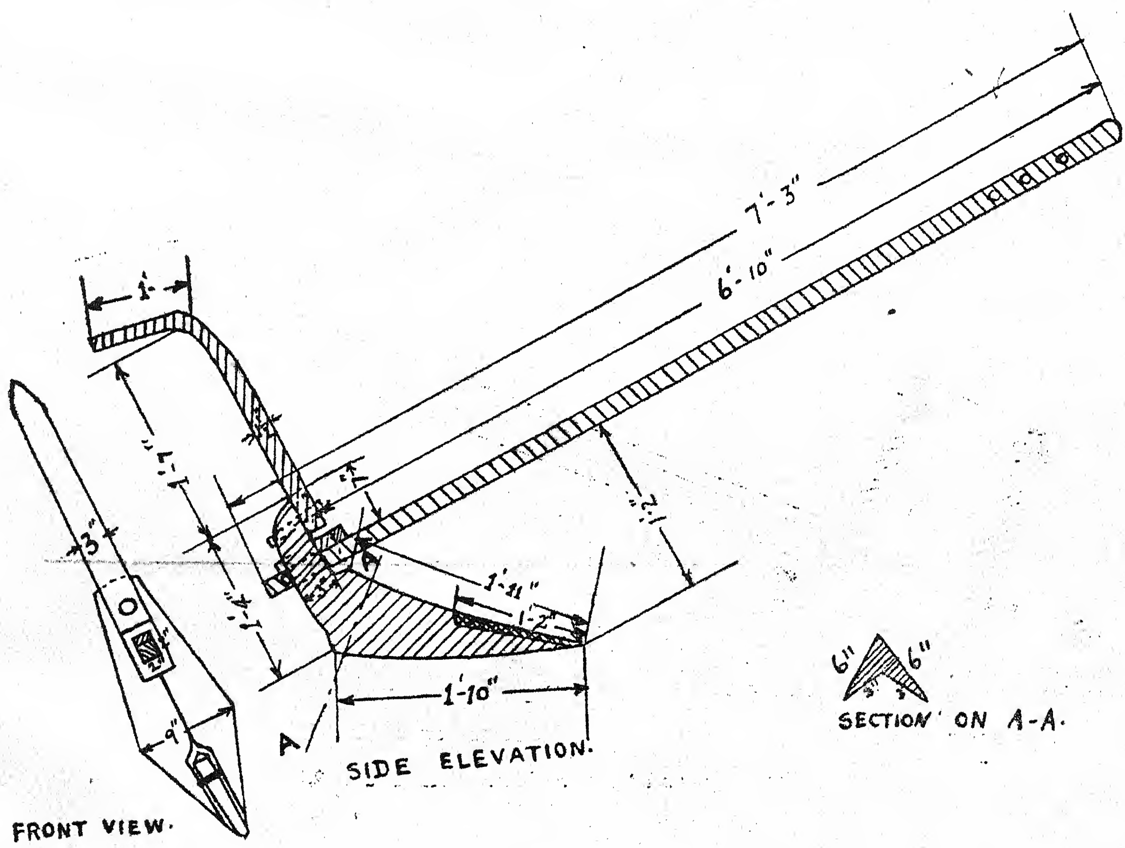


Fig. 27. Wooden plough, Tipperah (Bengal)

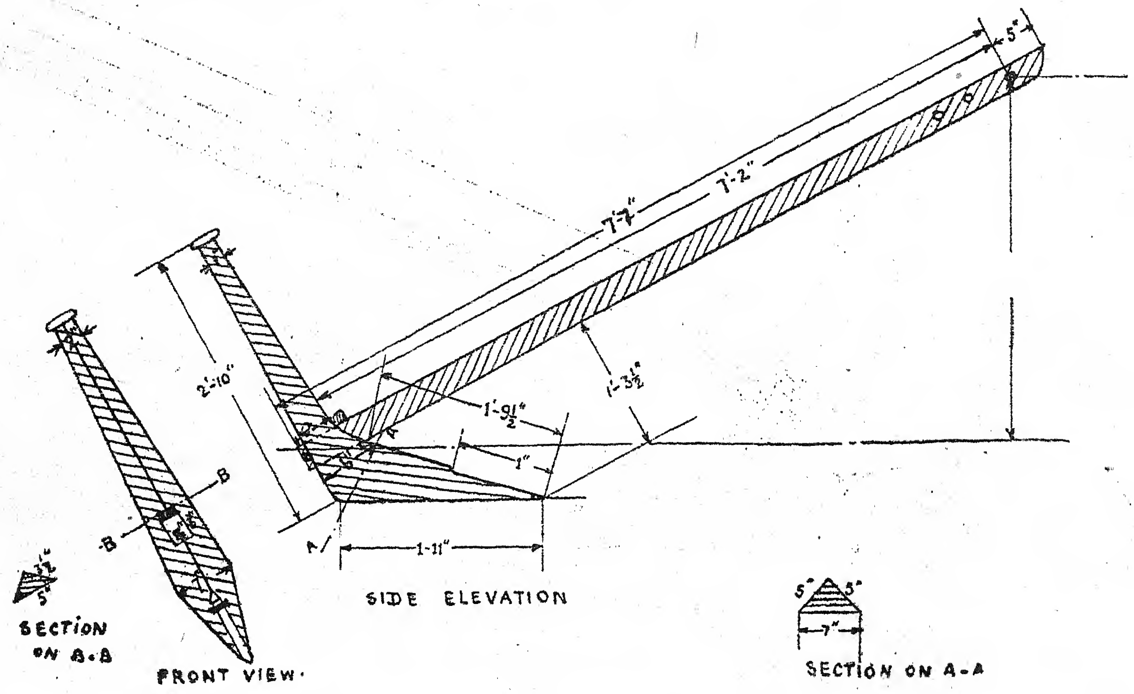


Fig. 28. Country plough, Rangpur (Bengal)

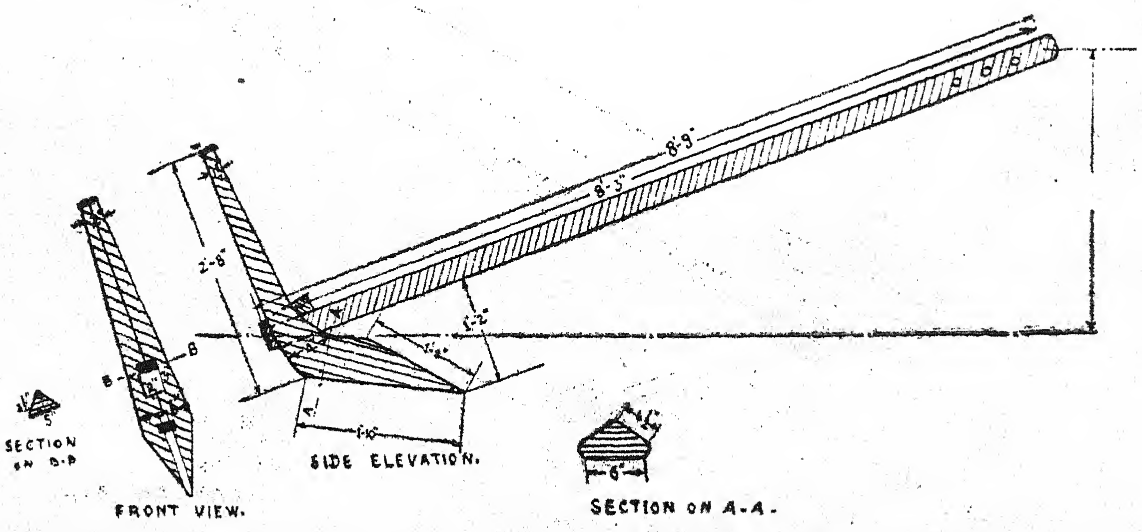


Fig. 29. Country plough, Dacca Farm (Bengal)

used in rainfed areas only and the average rainfall is as follows: January = 0·29 in., February = 1·08 in., March = 2·95 in., April = 6·58 in., May = 11·77 in., June = 18·05 in., July = 15·05 in. August = 14·91 in., September = 10·93 in., October = 6·52 in., November =1·03 in., and December = 0·23 in. A pair of local bullocks with a live weight 500 lb. each is used to work this plough.

(29) *Country plough, Rangpur* (*Bengal*). The dimensional diagram is given in Fig. 28. The wedge, the body and the handle are made in one piece. The beam is fixed to the body very near the inner bend and is of rectangular cross-section $1\frac{1}{2}$ in. × 3 in., its length being 7 ft. 7 in. The body is a solid of triangular cross-section. The wedge is a pyramid of triangular cross-section with sides 7 in., 5 in., and 5 in. and with vertex facing upwards. The length of the wedge up to the body is $21\frac{1}{2}$ in. and up to its intersection with the beam is 24 in. The face angle of the wedge is 19·2° and the angles which the wedge makes with the body and beam are 138° and 46·2° respectively. A small share is used in this plough. The weight of the plough is 20 lb. This plough is used in new alluvial soil with light texture of sandy Tista silt of Rangpur district. The crops generally grown are mostly transplanted paddy and jute. Ploughing is usually done to a depth of 3 in. to 4 in. when the moisture is between 15 to 20 per cent. It is used mostly in rainfed areas and the average rain is as follows: January = 0·06 in., February = 1·27 in., March = 0·41 in., April = 1·92 in., May = 14·72 in., June = 14·69 in., July 19·35 in., August = 17·59 in., September = 11·20 in., October = 5·23 in., November = 0·11 in., and December = 0·23 in. A pair of local bullocks with a live weight 470 lb. each is used to work this plough.

(30) *Country plough, Dacca Farm* (*Bengal*). The dimensional diagram is given in Fig. 29. The body wedge and handle are made in one piece. The beam is of rectangular cross section 2 in. × 3 in. and its length is 8 ft. 9 in. The body is a solid of triangular cross-section and the design of the plough is similar to that of Rangpur. The wedge is a pyramid of triangular cross-section, with its edges slightly curved. The sides of cross-section at maximum section are 6 in., 4 in. and 4 in. and the vertex facing upwards. Part of the vertex near the penetrating point is considerably flattened to fix the share. The vertex facing upwards is straight up to maximum section which is at a distance of 20 in. from the penetrating points of the wedge and afterwards it is curved. The length of the wedge up to the outer bend is 22 in. and up to its intersection with the beam is 24 in. The face angle of the wedge is 14° and the angles which the wedge makes with the body and beam are 135° and 45·6° respectively. The length of the share is 12 in. and the weight of the plough is 23·9 lb. This plough is used in red soils of heavy texture, old and new alluvial soils with light texture of Dacca district. The crops generally grown are paddy (transplanted and broadcast too), jute, pulses, wheat and barley. Ploughing is done to a depth of 3 in. to 4 in. when the moisture is about 15 to 20 per cent and the plough is used under waterlogged condition. The plough is used mostly in rainfed areas and the average rainfall is as follows: January = 0·17 in., February = 1·89 in., March = 0·97 in., April = 3·09 in., May = 12·97 in., June = 15·17 in., July = 10·26 in., August = 15·47 in., September = 7·59 in., October = 3·15 in., November = 0·46 in., and December = 0·34 in. A pair of local bullocks with a live weight of 500 lb. each is used to work this plough.

(31) *Orissa plough, Potangi* (*Orissa*). The dimensional diagram is given in Fig. 30. This design is absolutely different from the others. There is no bend between body and wedge and hence we can say that the wedge itself acts as body also. The beam is directly fixed to the wedge at a distance of 18 in. from the pointed end. The beam is of circular cross-section and is bent at the end where it is fixed to the wedge, and is straight for the remaining length. The total length of the beam is 8 ft. A separate curved wood piece is used as handle and is fixed to the wedge at the back of the beam. The wedge is a solid cone and its solid angle is 5°. The length of the wedge is 30 in. and maximum diameter of the cone is $2\frac{1}{2}$ in. The wedge is slightly chipped at the pointed end and a share of 6 in. length used. The weight of the plough is 19·2 lb. Angle between the wedge and the beam is 40°.

(32) *Orissa plough, Udayagiri* (*Orissa*). The dimensional diagram is given in Fig. 31. The wedge, body and handle are made in one piece. The beam is fixed to the body at a distance of 2 in. from the inner bend and is circular in cross section with 3 in. diameter. Its length is 7 ft. 6 in. The wedge is a pyramid with pentagonal cross-section with sides $5\frac{1}{2}$ in., $1\frac{1}{2}$ in., $3\frac{1}{2}$ in., $3\frac{1}{2}$ in and $1\frac{1}{2}$ in. at maximum section and the vertex facing upwards. The face angle of the wedge is

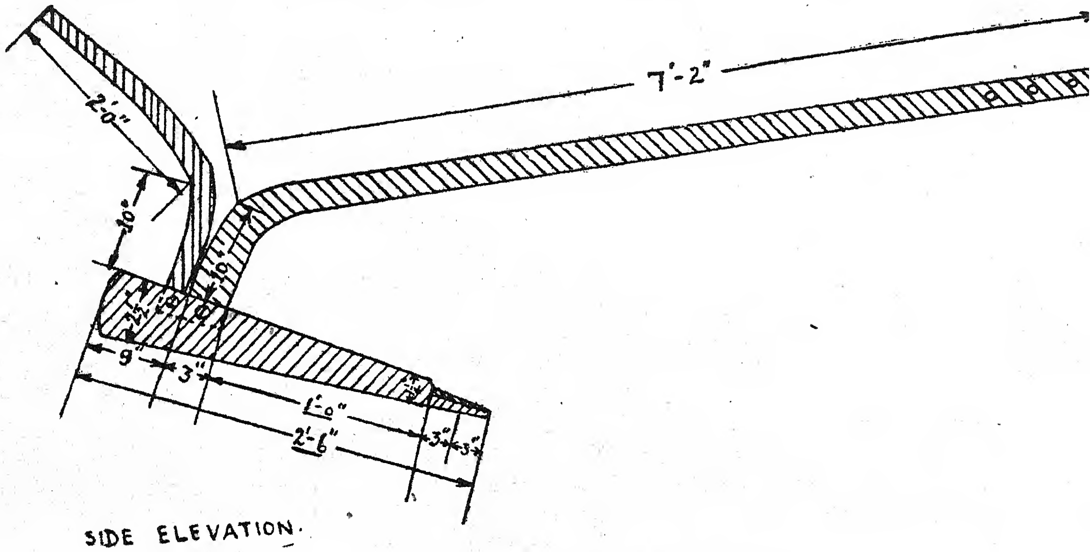


FIG. 30. Orissa plough, Potangi (Orissa)

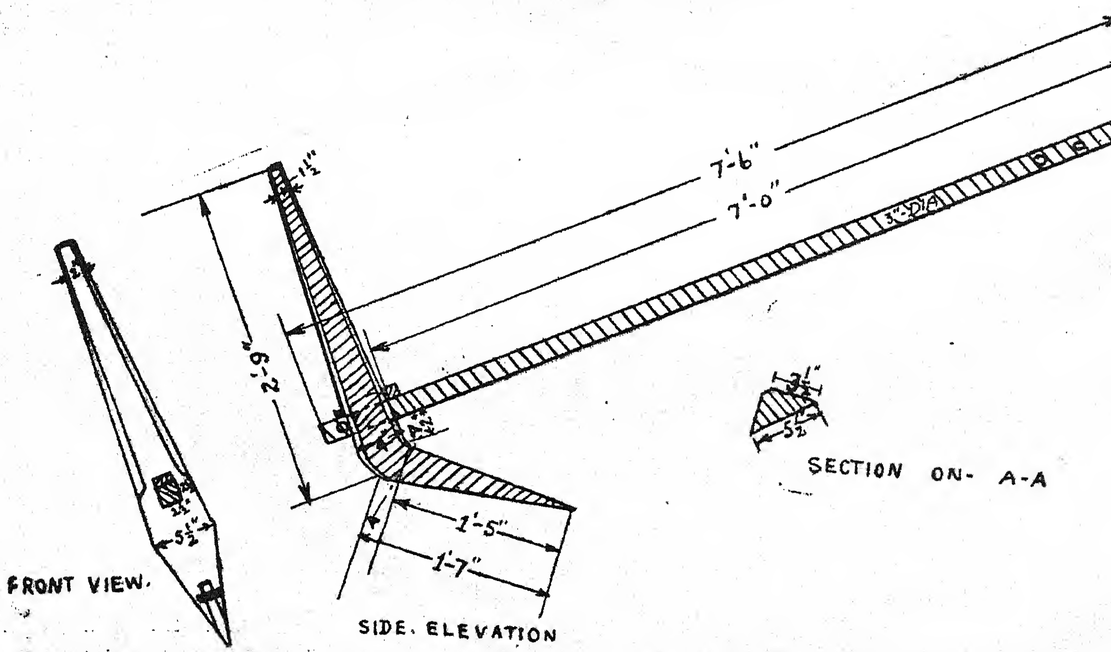


FIG. 31. Orissa plough, Udayagiri (Orissa)

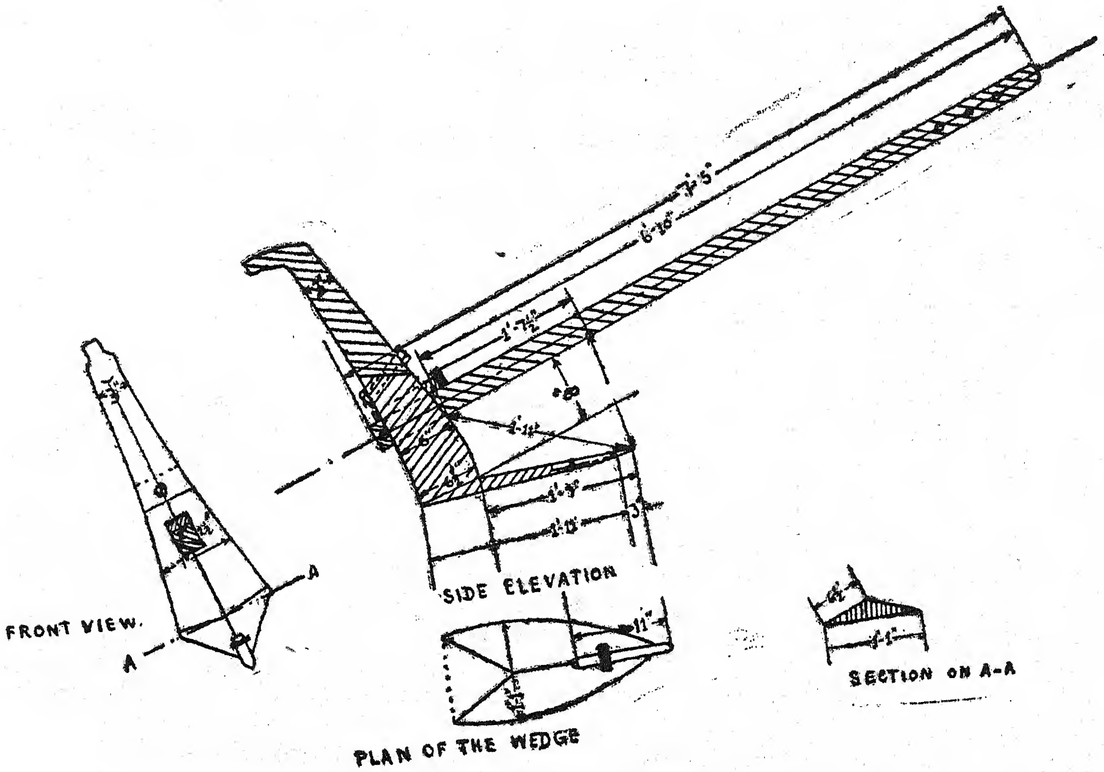


FIG. 32. Country plough, Sambalpur (Orissa)

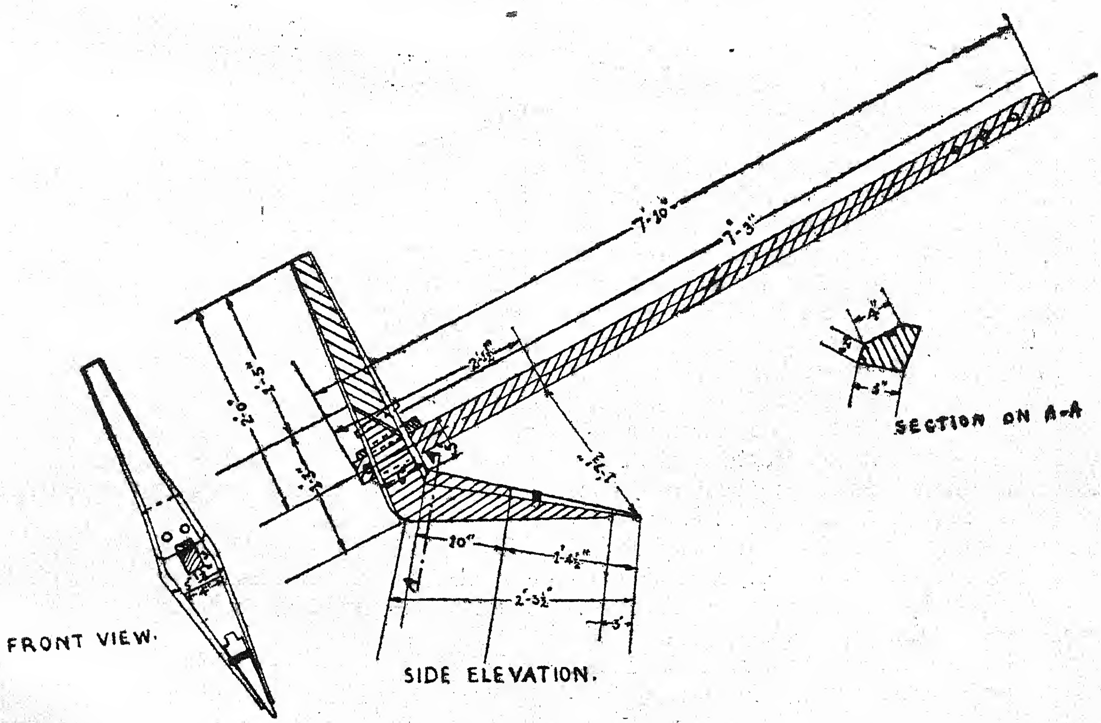


FIG. 33. Wooden plough, Berhampore (Orissa)

18·6° and the angles which the wedge makes with the body and beam are 120° and 49·9° respectively. The length of the wedge up to body is 17 in. and up to its intersection with the beam is 22 in. The length of the share is 9 in. and the weight of the plough is 17·2 lb.

(33) *Country plough, Sambalpur* (*Orissa*). The dimensional diagram is given in Fig. 32. The body and wedge are in one piece. The beam is fixed to the body at a distance of 8 in. from the inner bend and is of rectangular cross-section 2 in. × 2½ in., its length being 7 ft. 5 in. A separate handle is fixed to the body. The wedge is a pyramid of triangular cross-section with sides 13 in., 6½ in. and 6½ in. at maximum sections. The two edges are curved slightly. The length of the wedge up to the body is 20 in. and up to its intersection with the beam is 32 in. The face angle of the wedge is 40° and the angles which the wedge makes with the body and the beam are 140° and 30° respectively. The length of the share is 11 in. and the weight of the plough is 19·2 lb. The plough is used for puddling paddy fields. The average rainfall is as follows: January = 0·41 in., February = 0·79 in., March = 0·94 in., April = 0·65 in., May = 1·25 in., June = 10·92 in., July = 20·02 in., August = 19·19 in., September = 8·51 in., October = 2·00 in., November = 0·83 in., and December = 0·22 in.

(34) *Wooden plough, Berhampore* (*Orissa*). The dimensional diagram is given in Fig. 33. The body and wedge are made in one piece. The beam is fixed to the body at a distance of 1 in. from the inner bend and is of rectangular cross-section 2 in. × 3 in., its length being 7 ft. 10 in. A separate piece of wood is fixed to the body to serve as handle. The wedge is a solid of pentagonal cross-section with sides 5 in., 2 in., 4 in., 2 in. and 5 in. at maximum section and with the 4 in. side facing upwards. The length of the wedge up to body is 26½ in. and up to its intersection is 31 in. The face angle of the wedge is 17° and the angles which the wedge makes with the body and beam are 135° and 41·3° respectively. The length of the share is 16½ in. and the weight of the plough is 36·4 lb. The average rainfall is as follows: January = 0·35 in., February = 0·88 in., March = 1·07 in., April = 1·40 in., May = 5·51 in., June = 10·04 in., July = 10·85 in., August = 11·95 in., September = 10·12 in., October = 4·20 in., November = 0·62 in., and December = 0·12 in.

(35) *Orissa plough, Bhadrak*. Similar to Sambalpur in design.

(36) *Orissa plough, Angul*. Similar to Sambalpur plough in design.

Experiment

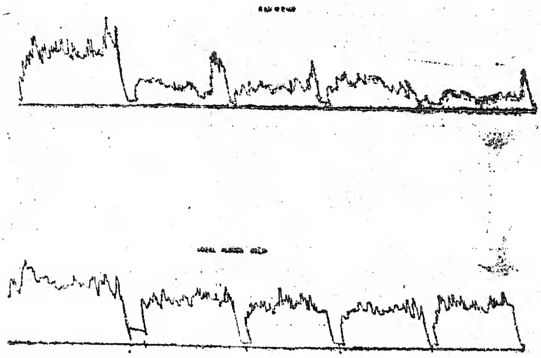
With the object of making comparative study of the Indian ploughs and also to investigate the fundamental principles involved in their design, dynamometer experiments were conducted in January 1941 with 40 ploughs, collected from different parts of India, which are described above. The field used for this experiment was plot No. 3 Main Block Farm area, Imperial Agricultural Research Institute, and the soil is sandy loam. The plot was level and had been ploughed and left fallow for two months before this experiment. The data were collected as follows: Five furrows, each 100 ft. long, were opened in succession by each of the ploughs, the first one being an opening furrow while the remaining four furrows followed as normal ploughing. Same ploughman and the same pair of Sahiwal bullocks were used throughout the experiment. Charts showing the draw-bar-pull (D. B. P.) fluctuations throughout the length of the furrow were obtained for each furrow with the help of a self-recording dynamometer. The description of the dynamometer is given in Appendix I. The average draw-bar-pull (D. B. P.) for the different furrows was calculated by computing the area included in-between the curve and the base line by means of a planimeter and dividing this area by the length of base line and multiplying the quotient by dynamometer constant. Specimens of the D. B. P. curves obtained for two of the ploughs are given in Fig. 34. In addition to the draw-bar-pull, the depth and width of each furrow were recorded by taking measurements at three points selected at random in each furrow. The moisture content was also determined by taking soil samples from each furrow. The total width covered by five furrows and the time taken to open each furrow were also noted. The angle between the beam and the ground line was calculated by noting the length of the beam and the height of the free end of the beam above the ground line when the plough was in working position.

Table I summarizes in brief the results of this experiment. The different ploughs have been arranged in ascending order of draw-bar-pull.

Discussions

From the examination of diagrams of all ploughs it can be seen that there is considerable difference

Ranghpur



Local plough Delhi
FIG. 34. Specimens of the D.B.P. curves

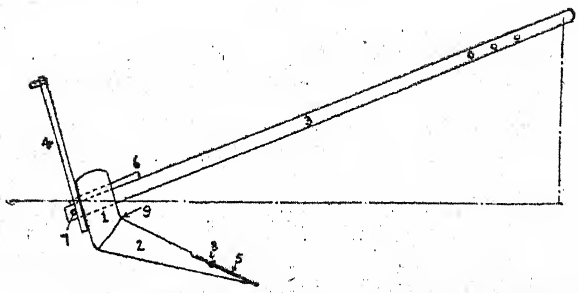


FIG. 35. Side elevation view of an Indian plough
1. Body, 2. Wedge, 3. Beam, 4. Handle, 5. Share or iron rod, 6. Cotter or small wedge, 7. Pin, 8. Ring to hold the share in position, 9. Inner bend
*These notations have been used throughout this paper

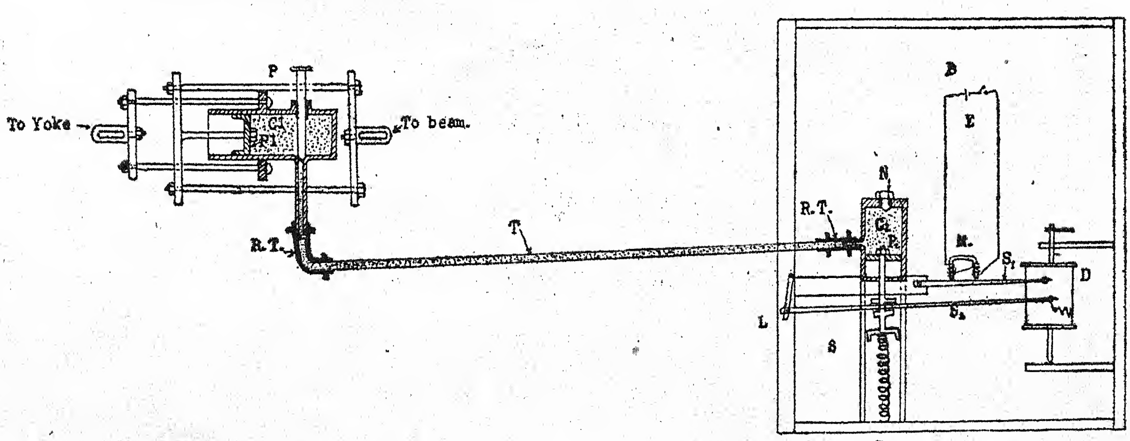


FIG. 36. The sectional view of the dynamometer

C1=Main cylinder
C2=Auxiliary cylinder
P=Pin to control the flow of oil from main to auxiliary cylinder
P1=Main piston
P2=Auxiliary piston
T=Metal tube
R.T.=Rubber tubes (special) for joining purpose
S=Spring
S1=Stylus No. 1
S2= ,, ,, 2
L=Lever
N=Nut to close the oil inlet of auxiliary cylinder
M=Electro magnet
B=Battery
D=Paper drum on which stylus No. 2 records the movements of the P2 which is proportional to the pressure on oil

TABLE I*

Summary of observational data

Name of the plough	Average moisture percentage	Average width of the furrow in inches	Average depth of the furrow in inches	Area of the cross section of furrow	Time taken in seconds to travel 100 ft. furrow	Plough angle, i.e. angle between beam and wedge	Angle which the beam makes with horizontal	Ploughing angle, i.e. inclination of wedge to the horizontal	Weight of the plough in lb.	Resistance per sq. inch based on first furrow	The length of the beam in ft. and in.	The length of the wedge up to body in inches	Draw-bar-pull for the first furrow in lb.	Average draw-bar-pull for the 4 successive furrows in lb.	H. P. on the basis of first furrow	H. P. on the basis of subsequent furrow
1. Country plough Kakori	8·92	7·00	3·83	13·40	31	30·00	..	..	25·88	2·55	9—5	..	35·68	27·9	0·22	0·17
2. Country plough Gorakhpore No. 1	9·5	8·2	5·5	22·55	27	40·00	..	..	18·2	1·59	9—4	16·0	35·9	40·9	0·25	0·29
3. Country plough Bareilly No. 1	10·36	6·66	4·00	13·37	29	33·05	23·6	9·45	24·00	4·40	8—9	..	58·6	62·6	0·37	0·40
4. Local plough Chotanagpur Purelia	8·36	9·83	6·00	30·47	28	48·60	20·4	28·20	25·10	2·16	7—10	20·0	65·9	46·0	0·43	0·30
5. Local plough Chotanagpur Ranchi	10·67	10·00	5·20	26·00	30	39·05	23·3	15·75	16·40	2·81	6—6	14·0	70·5	48·8	0·43	0·30
6. Orissa plough Udayagiri	8·59	10·33	6·00	30·99	23	49·90	20·4	29·5	17·20	2·65	7—5	17·0	82·3	55·4	0·65	0·44
7. Local plough Chotanagpur Daltanganj	8·78	10·83	6·00	32·50	25	39·80	22·9	16·9	30·20	2·62	8—7	..	85·1	84·5	0·62	0·62
8. Country plough Pusa Farm	9·17	10·20	6·50	33·15	25	44·90	24·9	30·0	34·34	2·66	8—1	13·0	88·2	60·7	0·63	0·43
9. Orissa plough Sambalpur	8·28	12·33	4·83	29·77	32	..	21·2	..	19·20	3·02	7—6	16·0	89·8	32·6	0·51	0·19
10. Wooden plough Tipperah	9·26	9·33	5·33	24·87	28	..	20·7	..	28·00	3·83	7—4	22·0	95·3	100·2	0·62	0·65
11. *Desi* plough Gorakhpore No. 2	9·25	8·66	7·00	30·30	31	45·00	20·0	25·00	22·00	3·58	9—2	12·0	108·6	102·5	0·64	0·60
12. Orissa plough Bhadrak	9·58	11·83	5·20	30·76	35	43·45	24·0	19·40	19·50	3·58	7—8	19·0	110·2	106·7	0·58	0·56
13. Wooden plough Gorakhpore	9·15	9·66	6·33	30·57	30	45·00	20·0	25·00	22·66	3·86	9—3	15·0	118·0	124·5	0·72	0·76
14. Orissa plough Angul	8·72	11·20	6·00	33·60	26	43·45	24·0	19·40	24·10	3·60	7—1	19·0	121·2	103·8	0·85	0·73
15. Local plough Chotanagpur	9·00	8·33	5·83	34·30	26	49·65	19·9	29·75	34·88	3·70	9—2	21·0	125·0	105·5	0·88	0·74
16. Country plough Rangpur	9·56	9·00	5·67	25·5	25	46·15	27·1	19·05	20·0	4·96	7—6	23·0	126·5	35·3	0·82	0·23
17. Country plough Bankura	9·81	12·00	6·33	37·98	27	41·85	23·05	18·8	31·0	3·36	8—5	19·5	127·7	147·1	0·86	0·99
18. Native Sind plough Mirkapur	8·51	9·00	6·67	30·0	32	46·81	30·0	16·81	35·4	4·43	9—4	20·0	133·0	95·0	0·76	0·57
19. *Desi* plough Gorakhpur No. 3	9·5	9·00	6·60	29·70	30	49·1	26·1	28·0	23·57	4·51	8—9	20·0	134·0	122·1	0·82	0·75
20. Wooden plough Berhampore	9·3	10·0	7·66	38·8	28	41·3	27·1	14·2	36·4	3·51	7—10	26·5	134·4	143·3	0·88	0·94
21. Kannar plough	9·11	12·33	6·66	60·05	36	48·1	22·9	25·2	37·9	2·40	9—5	..	144·0	160·7	0·75	0·84
22. Local plough Chotanagpur, Netarhat	9·12	12·0	5·33	45·98	26	48·35	21·7	26·6	41·8	3·25	9—7	26·5	150·7	76·4	1·06	0·54
23. Local plough Delhi	9·3	10·8	6·42	34·67	29	41·3	20·4	20·9	59·4	4·44	9—1	..	153·8	145·9	0·99	0·94
24. Country plough Patna	10·48	11·00	7·67	42·19	27	39·5	23·1	16·4	24·8	3·89	8—11	22·5	164·5	119·5	1·11	0·81
25. Country plough Aligarh	9·18	9·83	7·83	37·65	34	44·4	24·4	20·0	29·2	4·41	9—5	18·0	166·2	173·0	0·89	0·93
26. Country plough Jhansi	9·62	7·66	6·5	24·9	32	..	21·6	..	44·1	6·72	..	26·0	167·4	134·1	0·96	0·77
27. Country plough Oudh	9·98	7·83	7·00	27·4	29	..	23·6	..	17·0	6·10	7—11	..	167·3	135·2	1·05	0·85
28. Plough Dacca Farm	9·45	9·33	7·0	32·66	28	45·6	20·7	24·90	23·9	5·57	7—4	22·0	182·0	184·8	1·18	1·20
29. Native plough Sabour	9·09	11·5	7·83	45·0	30	45·5	20·5	25·1	44·1	4·62	9—5	28·0	208·0	220·9	1·27	1·35
30. Country plough Bareilly No. 2	9·09	8·66	7·16	31·0	42	45·1	22·0	23·1	25·1	7·30	9—1	22·5	226·2	261·24	0·98	1·13
31. Country plough N.-W. F. P.	8·8	11·2	7·0	39·2	40	..	21·4	..	47·8	6·98	9—3	16·0	273·5	245·1	1·25	1·12
32. Orissa plough Potangi	8·61	8·0	8·33	33·32	30	26·35	20·7	5·65	19·2	8·80	7—8	18·0	293·2	191·2	0·92	0·60
33. Local plough Karnal	8·4	12·0	8·2	49·2	29	44·5	21·5	23·0	51·6	6·00	10—11	22·0	295·9	296·6	1·86	1·87
34. Victory plough	8·06	12·33	5·83	71·88	40	..	20·4	..	80·0	4·19	12—0	..	299·0	360·6	1·36	1·64
35. Country plough Baroda	8·34	11·5	8·0	46·0	33	37·60	19·6	18·06	50·7	6·63	11—4	23·0	305·6	261·57	1·69	1·45
36. Sarkar plough Sind	9·12	12·33	8·00	61·00	34	43·0	22·5	20·45	33·3	5·00	11—5	..	305·0	236·1	1·64	1·27
37. Country plough Coimbatore	8·64	11·0	9·0	49·5	35	40·96	22·0	18·96	37·4	6·82	11—7	29·0	228·0	328·0	1·76	1·71
38. Country plough Dohad	7·66	9·33	9·33	43·5	24	43·00	21·4	21·53	28·7	8·28	9 4	18·0	260·0	350·0	2·73	2·65
39. Heavy country plough Bellary	9·11	9·66	9·00	43·3	46	42·2	..	..	81·5	8·90	9—2	32·0	387·5	390·0	1·54	1·55
40. Country plough Indore	8·28	9·63	10·66	51·5	43	42·5	21·3	21·2	56·9	8·08	10—4	20·0	416·0	403·5	1·76	1·71

* The help rendered by Mr A. K. Kaul, Engineering Assistant, Imperial Agricultural Research Institute, in maintaining the dynamometer is gratefully acknowledged.

between the ploughs in their construction. The following are the main differences:

1. In some of the ploughs the body and wedge are made in two parts and have been assembled together, while in others they have been made in a single piece. In the former case if the wedge is damaged it can be replaced, and at the time of constructing the body and wedge very little wood is wasted. The angle between the body and wedge can easily be altered whenever required, as the tightening of these parts is done with the help of the cotters or pegs, while the angle between the body and wedge in the other type cannot be altered. Any wood can be used subject to the strength of the material to withstand the forces acting on the plough due to the soil. In other types a wood which is quite hard and has very little wear and tear like acacia should be used. In the first type, however, the wedge is likely to get loosened soon and cause damage to the body as the tightening is done by cotters.

2. In some ploughs the beam is fixed to the body at a farther distance from the bend between the body and wedge, while in others it is very near. The advantage in the former case is that when the plough is working in a field full of weeds, the weeds do not cause any undue increase in draught by sticking to the plough and blocking the passage of the plough. Besides this, the depth of ploughing will be greater than in the latter case provided the length of wedge and the plough angle are same in both cases.

3. The wedges are broad ana short in some cases while in others they are narrow and long. The ploughs with broad and short wedges are used in soils where moisture is high, i.e. generally for puddling, in which case the cutting force is less. If the ploughs with long and narrow wedges are used in soils with high moisture content, they will penetrate to a greater depth due to which the draught will be more. While cutting with narrow wedges the sides of the furrows will be intact (i.e. the disturbance of the soil near the side of furrows is very little) and produce a side pressure on the wedge of plough which will cause an increase in the frictional resistance. Therefore, the total resistance per unit area of cross-section of the furrow opened is greater in the case of ploughs with narrow wedges than that of the ploughs with short and broad wedges. The disadvantage of ploughs with broad and short wedges is that they plough the land to a lesser depth than the other case.

4. In certain ploughs the wedges are solid pyramids with triangular cross-section while in others they are of different shapes, some conical, some trapezoidal frustums and others solid cones having a cross-section like segment of an ellipse (cut by a line parallel to its minor axis). In the former type the vertex of cross-section faces downwards.

Examining the ploughs from their construction point of view it will be seen that a classification on constructional basis can mainly be done from the point of their wedges on which the working capacity of a plough depends. Applying this criterion the following classification has been made:

(1) *Ploughs with broad and short wedges with triangular cross-sections.* Sambalpur, Angul, Bhadrak and Bankura ploughs will fall in this class. They are similar not only in their wedges but in the attachment of their beams to the bodies and in other constructional points of view. The Bankura plough has a slightly longer and narrower wedge than the others. The body and the wedge are made in one piece.

(2) *Ploughs with broad and long wedges with triangular cross-section.* Native plough Sabour falls in this class. The body and the wedge are made in one piece.

(3) *Ploughs with broad trapezoidal frustum wedges.* Local plough Chotanagpur Netarhat and local plough Chotanagpur come in this class. They have no bodies. Sarkar plough Sind and North-West Forntier Province plough with their trapezoidal wedges can also be placed in this class. But the beam of the North-West Frontier Province plough is curved and the coulters of Sarker and North-West Frontier Province ploughs are flat iron plates. The body and wedge are made in one piece.

(4) *Ploughs with long wedges of medium breadth with triangular cross-section.* Bellary, Coimbatore and Berhampore ploughs will come in this class. In the case of Bellary ploughs the cross-section of the wedge is triangle. The vertices of the cross-section of the wedge of Coimbatore plough are slightly flattened while that of Berhampore plough are flattened in such a way that the section has become pentagon. Jhansi plough also can be placed in this class, but one of the vertices of the cross-section of the wedge has been rounded and this curved face faces downwards. The beam of the Jhansi plough is curved. The body and wedge are made in one piece in this also.

(5) *Ploughs with specially designed wedges.* *Desi* plough Delhi and Local plough Karnal will come in this class. The wedge of Delhi plough is partly iron and partly wood. The iron part is a flat plate of triangular section ⅜ in. thick. The wooden part and the body are made in single piece. Similarly in the case of Local plough Karnal, the wedge is of two cross-sectional dimensions. Part of the wedge is a pyramid of segmental cross-section and the remaining part is a solid with sectoral cross-section as shown in diagrams.

(6) *Ploughs with wedges of medium length and width.* There are two sub-types in this class:

- (*a*) *Ploughs with body and wedge made in one piece*—Patna, *Desi* Gorakhpur No. 3, Wooden Gorakhpur, Country Pusa Farm, Chotanagpur Purelia, Ranchi, Dacca Farm, Rangpur and Udayagiri ploughs will come in this class. In the case of Dacca and Rangpur ploughs the edges of their wedges are slightly rounded.
- (*b*) *Ploughs with body and wedge made in two pieces*—*Desi* Gorakhpur No. 1, *Desi* Gorakhpur No. 2 and Aligarh ploughs will come in this class.

(7) *Ploughs with small and thin wedges.* Bareilly No. 1 and Kakori ploughs will come in this class. Their wedges are of insignificant size. They are probably used as harrows.

(8) *Ploughs with narrow and long wedges.* Country Dohad, Indore, Bareilly No. 2 and Baroda ploughs will come in this class. In Baroda plough the wedge is conical and different from that of others. The Potangi plough also can be placed in this class but the beam and handle are curved. There is no body and the wedge is a solid cone and resembles the primitive type.

(9) *Ploughs with bodies and shares made of iron.* Kannar plough will come in this class. The body and share are specially designed. The beam is wooden and the plough is a modified form of Victory plough.

Now coming to the classification on the basis of crops and the conditions of the soil at the time of ploughing, it can be seen that the following classification can be made.

(1) *Ploughs which are intended only for wet land paddy fields.* Sambalpur, Angul, Bhadrak, Bankura, Local plough Chotanagpur, L. P. Chotanagpur Netarhat, with their broad and short wedges, come in this class. In the case of wet land paddy fields, puddling is the main operation to prepare the soil for transplantation and this can be done under waterlogging conditions. So these ploughs are more useful than the ploughs with the narrow and long wedges. Sabour plough with slightly modified wedge can be placed in this class.

(2) *Ploughs which are intended for paddy fields and dry lands under various other crops.* Dacca Farm, Rangpur, Tipperah, Karnal, Sarkar Sind, Bellary, Coimbarote and *Desi*-Gorakhpur ploughs will come in this class. These ploughs are used for puddling paddy lands and also for ploughing the fields for other crops. Ploughing is done when the moisture content of the soil is sufficient to make it ploughable. If the moisture due to rain is insufficient, ploughing is done after irrigation. Karnal, Bellary, Coimbatore and Gorakhpur ploughs are used for preparing land for sugarcane also.

(3) *Ploughs which are intended for dry land crops only.* The remaining ploughs with long and narrow or medium wedges will come in this class. Some of these ploughs are used in rainfed areas only while others are used in both rainfed and irrigated areas. In these cases also ploughing is done when the moisture content of the soil is sufficient to make the soil ploughable.

The experimental results and the charts showing the draw-bar-pull indicate that the draw-bar-pull in the case of first furrow is more than in the case of subsequent furrows in many cases. But as it was very difficult to distinguish whether the subsequent furrows were made as in the case of normal ploughing, the investigations were confined mainly to data from the first furrows. However, the average draw-bar-pull for the successive furrows is also given in Table I for the purpose of comparison.

Taking the ploughs of the different groups mentioned above on crop basis, the values of width and depth of the furrows, the D. B. P. weight, of ploughs, resistance per unit area of cross-section, horse-power (H.P.) and time enable us to see which plough can be regarded as the best in the different groups.

In the case of Bankura plough the H. P. and the resistance per unit area of cross-section of the furrow are comparatively minimum, while the cross-section and the depth of the furrow are maximum. The wedge of this plough is more pointed than that of the others in this Group and this probably may be the cause for maximum depth. Besides this, the weight of the plough is quite sufficient to make it strong so that the plough can

GROUP I

Name of plough	Furrow		Weight in lb.	Time to open 100 ft. furrow in sec.	D. B. P. in lb.	Resistance	H. P.
	Width	Depth					
Sambalpur . . .	12·33	4·83	19·2	32	89·8	3·02	0·51
Angul	11·20	6·00	24·1	26	121·0	3·60	0·85
Bhadrak . . .	11·83	5·20	19·5	35	110·0	3·56	0·58
Bankura . . .	12·00	6·33	31·0	27	127·7	3·36	0·86
Local Plough Chotanagpur	8·33	5·83	34·3	27	125·0	3·70	0·88
L. P. Chotanagpur Netarhat	12·00	5·33	41·8	26	150·7	3·25	1·06
Sabour with modified wedge	Not tried	Not tried	Not tried	Not tried	Not tried	Not tried	Not tried

GROUP II

Name of plough	Furrow		Weight in lb.	Time in sec.	D. B. P.	Resistance	H. P.
	Width	Depth					
Rangpur . . .	9·00	5·67	20·0	25	126·5	4·96	0·82
Dacca Farm . .	9·33	7·00	23·9	28	182·0	5·57	1·18
Tipperah . . .	9·33	5·33	28·0	28	95·3	3·83	0·62
Desi Gorakhpur 3 .	9·00	6·60	23·6	30	134·0	4·51	0·82
Karnal . . .	12·00	8·20	51·6	29	295·9	6·00	1·86
Sarkar Sind . . .	12·00	8·00	33·3	34	305·0	5·00	1·64
Coimbatore . . .	11·00	9·00	37·4	35	338·0	6·82	1·76
Bellary . . .	9·66	9·00	81·5	46	387·5	8·90	1·54

be used for general ploughing operations in fields with proper moisture content. Hence the design of the wedge and construction of Bankura plough appears to be the best of this Group.

Group II can be divided into two sub-groups on depth basis. Rangpur, Dacca Farm, *Desi* Gorakhpur and Tipperah ploughs will come under first sub-group with depths between 5·33 to 7 in. Karnal. Sarkar Sind, Coimbatore and Bellary ploughs will come in the second sub-group with depths between 8 to 9 in. In the first sub-group, *Desi* plough Gorakhpur No. 3 can be considered to be the best. In the second sub-group the Sarkar Sind appears to be the best, but it is used in irrigated tracts only. Therefore, Karnal plough which is used under varying conditions, can be considered as the best design of this sub-group.

Group III

	Name of plough	Furrow		Weight in lb.	Time in sec.	D. B. P.	Resistance	H. P.
		Width	Depth					
I	1. Country plough Gorakhpur No. I.	8·2	5·5	18·2	27	35·9	1·59	0·25
I	2. Local plough Chotanagpur, Ranchi	10·00	5·2	16·4	30	70·5	2·81	0·43
II	3. Chotanagpur Purelia	9·83	6·0	25·1	28	65·9	2·16	0·43
II	4. Orissa plough, Udayagiri	10·33	6·0	17·2	23	82·3	2·65	0·65
II	5. L. P. Chotanagpur, Daltonganj	10·83	6·0	30·2	25	85·1	2·62	0·62
III	6. Country Pusa Farm	10·20	6·5	34·3	25	88·2	2·66	0·63
III	7. Wooden Gorakhpur	9·66	6·3	22·6	30	118·0	3·86	0·72
III	8. Native Sind .	9·00	6·7	35·4	32	133·0	4·43	0·76
III	9. Local plough Delhi	10·80	6·4	59·4	29	153·8	4·44	0·99
III	10. Jhansi . .	7·66	6·5	44·1	32	167·4	6·72	0·77
IV	11. *Desi* Gorakhpur	8·66	7·0	22·0	31	108·6	3·58	0·64
IV	12. Country Oudh	7·83	7·0	17·0	29	167·3	6·10	1·01
IV	13. Country N.-W. F. P.	11·00	7·0	47·8	40	273·5	6·98	1·25
IV	14. Country Bareilly 2	8·66	7·2	25·1	42	226·2	7·30	0·98
V	15. Wooden Berhampore	10·00	7·7	36·4	28	134·4	3·51	0·88
V	16. Country Patna	11·00	7·7	24·8	27	164·5	3·89	1·11
V	17. Country Aligarh	9·83	7·8	29·2	34	166·2	4·41	0·89
V	18. Native Sabour	11·50	7·8	44·1	30	208·0	4·62	1·27
VI	19. Country Baroda	11·50	8·0	50·7	33	305·6	6·63	1·69
VI	20. Orissa Potangi	8·00	8·3	19·2	30	293·2	8·80	0·92
VI	21. Country Dohad	9·33	9·3	28·7	24	360·0	8·28	2·73
VI	22. Country Indore	9·66	10·7	56·9	43	416·0	8·08	1·76

Group III can be divided into a number of sub-groups from the depth point of view as indicated in the above table. In the case of sub-group I, from H. P. and resistance point, Country plough Gorakhpur No. 1 seems to be better than the other one. In sub-group II, Chotanagpur Purelia appears to be the best of the lot. The weight is also quite sufficient to make it strong. In sub-group III, Country plough Pusa appears to be superior to any of the other ploughs. In sub-group IV, *Desi* plough Gorakhpur No. 2 requires much less D. B. P. and H. P. than any of the others. In sub-group V, Wooden plough Berhampore can be considered as the best. In sub-group VI, it will be seen that Country plough Baroda requires very strong bullocks while Potangi can be worked with average bullocks. In the above cases the ploughs which are considered to be the best can also be worked with average bullocks. Between the ploughs of Dohad and Indore, the design of Indore appears to be better.

Summary

Ploughs collected from different parts of India have been examined from constructional, crop, draw-bar-pull depth of ploughing, resistance per

unit area of cross-section of furrows and horse-power (H. P.) points of view, and attempts have been made to classify them on these basis. The draw-bar-pull charts, the depth and width of furrows, the time taken to open 100 ft. furrow were obtained by working the ploughs in the same field with the same pair of bullocks and ploughman and hence the deductions drawn from this experiment are purely comparative. The resistance and H. P. were calculated from D. B. P. depth and width of furrows and time.

In order to have a more definite classification the experiment should be repeated in different soils and comparison should be made on the above basis.

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Aeppndix 1

Description of the dynamometer

A sketch of the dynamometer used for ploughing experiments is given in Fig. 36. It will be seen that it consists of two main parts, viz.

(i) A hydraulic link composed of a well-fitting main piston and a cylinder, connected by means of a metallic tube to an auxiliary cylinder fitted with a piston kept in a position by a spring S. The intervening space between the two pistons is completely filled with oil.

(ii) A self-recording arrangement which consists of a paper roll mounted on two spindles (not shown on diagram), and a drum provided with a mechanism for moving the paper at any desired speed.

One end of the hydraulic link is connected to the yoke and the other to the beam. The pull exerted by the bull is transmitted to the oil in the auxiliary cylinder by the transference of oil from the main cylinder through the connecting tube which causes the auxiliary piston to move. The movement of this piston is recorded on a special paper roll by means of a stylus S_1 connected to the auxiliary piston with a lever. When the plough is in continuous operation, the drum is rotated and the stylus S_1 leaves a continuous mark on the paper. In order to obtain a legible impression on the paper the pressure exerted on the paper by stylus should be adjusted by the screw provided for this purpose. Another stylus S_2 operated electrically by a dry cell can be used to mark points on the paper at any desired intervals. This will enable us to calculate the speed at which the plough is being worked at any interval (provided the paper and plough are moving at a definite speed).

Knowing the length of the ordinate of the curve above the base line at any instant, the D. B. P. at that instant can be calculated by multiplying it with the compressive value of the spring which is usually represented as so many pounds per inch of compression.

REVIEW

Annual Review of Biochemistry and Allied Research in India, Vol. XIII for 1942

(Society of Biological Chemists, India, Bangalore, Rs. 3 or 6s.)

INVESTIGATIONS in Biochemistry and allied subjects during 1942, are reviewed under 11 sections and cover varied fields of research. Each of these reviews draws attention to the increased volume of work. The important contributions made in the field of enzymes relate to the nature of the proteolytic systems in the whole blood, amylase inhibition by vitamin C, phosphates in seeds and the isolation of an enzyme from *Withamia Coagulanus*, an easily available substance in the market, for the preparation of rennet. Mention is made of the investigations which showed that phosphates content of milled rice is two-thirds that of hand-pound rice. It is also suggested that milling standards for rice can be established on the phosphates content of rice samples.

Under vitamins about 400 papers dealing with vitamin A, B, C, riboflavine and nicotinic acid are reviewed. Reference is made to the interesting experiments which showed that parboiled rice contained on the average four times as much vitamin B as washed raw rice and that wheat and millets generally contain their vitamin in the free state while pulses contain varying amounts of combined vitamins.

Widespread famine in different parts of the country raises the question of combating vitamin deficiency diseases and this problem has become more acute due to the scarcity of the imported vitamin concentrates due to war conditions. Work done in this direction is reviewed under the section of General Nutrition. It was found that Bengal gram contained 6 to 20 mg. of vitamin C per 100 gm. and that this vitamin is rapidly formed during germination reaching a maximum in 30 to 48 hours after which it remains stable for 3 to 4 days. It was shown that dehydrated foodstuffs are too low in vitamin C to be of practical importance and that of all the dehydrated fruits *amla* (*Phyllanthum emblicalin*) is unique in the sense that potent dry powder can be prepared having a potency of about 25 to 30 mg./gm. of vitamin C. The suggestions made for improving the present unsatisfactory state of food situation in India, to mention a few, are the manufacture of shark liver oil, the production of yeast and yeast extracts in India as substitutes for marmite and imported yeast products, the diversion of part of land at present used for money crops to food crops, the prohibition of polishing of rice and the harnessing of scientific methods in agriculture, animal husbandry and fisheries.

In the domain of human physiology the work reviewed relates among other subjects to the age estimation, blood chemistry, blood groups, health investigations, circulatory, digestive, reproductive and respiratory systems.

In the field of animal nutrition reference is made to the suggestion that in crop planning adequate attention should be paid to the needs of the cattle especially the dairy cow. The possibilites of growing giant star grass in India for fodder supply and erosion control are indicated. Investigations over the variations in the composition of berseem with the state of growth, the effect of maturity of some cereal plants, the carotene content of plant materials with special reference to hay making and storage, are also reviewed. Mention is made of the work on the applicability of the freezing point test for detecting the adulteration of cow's and buffalo's milk and methods of preparing cheese of good quality.

The subject of human pathology continued to receive attention. Researches were carried out on dysentery, cholera, digestive system, endocrine glands, kala-azar, leprosy, plague, syphilis, typhus and several other diseases.

In plant physiology the reviews relate to nutrition, photosynthesis, chlorophyll, effect of radiation, reproduction, hormones, disposal of waste products and to ecology of diseases.

In the subject of chemistry of plant products investigations were carried on essential oils, fixed oils, sterols and lactones, plant colouring matters, alkaloids and glucosides, and the HCN content of giant star grasses.

Growing interest is evinced in the manifold problems presented by soils. Work reviewed relates to soil survey and soil classification, soil

colloids and physico-chemical properties, movement of moisture and salts, soil swelling and shrinkage, soil erosion, soil micro-organisms, nitrogen fixation in soils, and manures and fertilizers.

An important contribution reviewed under soil survey and classification is the preparation of the soil map of India which presents a general idea of evolutionary status of the Indian soils under varied geological and climatic conditions. Reference is made to the investigations on the effect of fertilizer treatments for a number of years on the permanent manurial plots at Pusa on the nature of soil micro-organisms and their activity and to the observed correlation between the crop yields and microbial activity. The work on cotton which showed that cotton seeds coated with dry ammonium sulphate before sowing gave better yields than when the manure was applied as top dressing or during drilling is also reviewed. Attention is drawn to the investigation on the availability of nitrogoen in soils with application of F. Y. M. under different conditions of moisture and C : N ratios on black cotton soil under continued cane growing, which showed that soils with wide C : N ratio did not respond to F. Y. M. as the mineralization of F. Y. M. in such soils was poor.

While this review contains a faithful record of the activities of Indian workers and as such, much valuable information can be obtained from it, its utility can further be enhanced by the reviewers making their reviews more complete by consulting the reports of the various Provincial agricultural departments and University magazines as well as the reports of the irrigation research laboratories and those of the private Research Institutions. Work published in Indian Journal of Pharmacy is not reviewed under either pharmacy or chemistry or plant products, work published in Journal of Malarial Institute of India is not reviewed in human pathology under malaria and that in Madras Agricultural Journal, Poona Agricultural College Magazine are not referred in soil and fertilizers, to mention a few instances of obvious omissions. The contribution on the geological evolution of Gujerat and study of the dietary and nutritional status, published in the Journal of the Gujerat Research Society missed the attention of the reviewers. Further, in some cases investigation on the same subject is reviewed by several reviewers under different heads while some investigations like those on fermentation are not reviewed in any of the branches. The work on nitrogen fixation by algae, review of nitrogen fixation, work on haemopoietic systems, uropoietic systems and the investigations on the relation between interval of cutting and yield and chemical composition of perennial grasses are reviewed in more than one place. A slight change in the divisions to be reviewed and a little editorial touching may eliminate these defects. It is fervently hoped that the reviews may be published at least within six months of the close of the year under review so as to make it more useful to the workers in the different branches of Biochemistry and allied subjects.—S.V.D.

MGIPC—M—III-1-9—21-5-45—600.